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CAPSULE ASSEMBLY FABRICATION
FINAL REPORT

by

A. R. Keeton, L. G. Stemann and G. G. Lessmann

Prepared for

National Aeronautics and Space Administration
NASA- Lewis Research Center
Nuclear Systems Division

Contract NAS 3-12978

Byron L. Siegel, Project Manager

Astronuclear Laboratory
Westinghouse Electric Corporation

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NASA Lewis Research Center
Cleveland, Ohio
Byron L. Siegel, Project Manager
Nuclear Systems Division

FOREWORD

The work described herein was done at the Astronuclear Laboratory, Westinghouse Electric Corporation, under NASA Contract NAS 3-12978, with Mr. Byron L. Siegel, Nuclear Systems Division, NASA-Lewis Research Center, as Project Manager. Mr. G. G. Lessmann was Project Manager for Westinghouse Electric Corporation while Mr. A. R. Keeton was responsible for program execution and control. Mr. L. G. Stemann was responsible for welding and brazing.

ABSTRACT

Irradiation test capsule assemblies were fabricated for evaluation of fuel pin design concepts for a fast spectrum lithium cooled compact space power reactor designed to operate at 1800°F clad temperature. Forty-one fuel pins and thirty instrumented capsule assemblies were fabricated in this program. These assemblies consisted of T-111 clad, tungsten lined, uranium mononitride fuel pins encased in stainless steel capsule assemblies. Double encapsulation was provided throughout, even for centerline thermocouple penetrations.

Fabrication procedures were fully qualified by process development and by assembly qualification tests. Instrumentation reliability was achieved utilizing a specially designed thermocouple hot zone subassembly. Ultimate overall capsule reliability was achieved with an all electron beam welded assembly.

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I. SUMMARY

Fuel pins and capsule assemblies fabricated in this program were designed by the Nuclear System Division of Lewis Research Center for evaluation of fuel pin design concepts for a fast spectrum lithium cooled compact space power reactor. A total of 41 fuel pins and 30 instrumented capsule assemblies were fabricated in this program for irradiation in the NASA Plumbrook Reactor Facility. These assemblies consisted of T-111 clad, tungsten lined uranium mononitride fuel pins encased in stainless steel capsule assemblies. Fuel temperature control was achieved by a stepped annular helium filled space between the fuel pin and capsule. Fuel enrichment was 8.2% for the 3/8 inch fuel pins and 5.6% for the 3/4 inch fuel pins. Double encapsulation was provided throughout even for the centerline thermocouple penetrations.

Work under this contract included development and qualification of fabrication techniques for the fuel pin and capsule, actual fabrication of capsule assemblies, and fabrication of a set of fuel pins for accelerated tests. The fuel pins designed for accelerated tests were subsequently encapsulated under contract NAS 3-14402. Hence, encapsulation of these fuel pins will be the subject of a future report.

A number of salient features contributed significantly to achieving success in this program. These deserve special attention:

- The most reliable assemblies were constructed entirely by electron beam welding (final vent holes sealed by GTA welding to achieve helium backfill).
- Special care was exercised in the design of thermocouples in the area of the hot zone so that they could accommodate considerable thermal cycling. In combination with stringent cleanliness standards and unique construction techniques, this design provided very reliable instrumentation.

- Uninterrupted final fuel pin assembly was accomplished in an electron beam weld chamber without ever exposing fuel to air or otherwise exposing pin components to air once assembly was initiated. Monitored ultrapure helium and vacuum atmospheres were alternately provided within the chamber as the assembly progressed through final fuel pin sealing.
- All assembly procedures were fully qualified.
- Complete and thorough documentation was maintained for each assembly on each component, procedure, inspection, and fabrication sequence.
- High cleanliness standards were observed throughout construction of capsule assemblies.
- A comprehensive thermal cycling qualification in ultrahigh vacuum proved instrumental in improving fuel pin reliability.
- Care was exercised in component fabrication to assure good dimensional control in critical areas.

II. INTRODUCTION

A technology program based on a fast spectrum reactor is being carried out by the Nuclear Systems Division at Lewis Research Center. This program involves design of the reactor structure, control devices, neutronics, materials compatibility studies, fuel elements and in-pile testing. The general reactor concept involves use of a lithium coolant, a refractory alloy fuel clad and structural material, and a fully enriched uranium nitride ceramic fuel. The reactor thermal power would be approximately 2.2 MW with a design life goal of 50,000 hours.

The first version of this concept would have a fuel pin clad operating temperature of about 1800°F (1255°K). T-111 tantalum alloy will be used as the fuel pin clad with a tungsten liner to prevent direct contact between the clad and the uranium nitride fuel.

The in-pile testing program for this reactor concept involves compatibility studies between different combinations of fuel, clad and liners, investigation of the effects of fission gas release and fuel swelling, demonstration of the feasibility of the fuel pin design (fuel pin proof tests) and evaluation of the effects of variable fuel density and higher temperatures on fuel pin performance. Irradiations are being conducted in the Oak Ridge Research Reactor and the NASA Plum Brook Reactor Facility.

In this contract fuel pins for the portion of the in-pile test program designated as the "Fuel Pin Proof Tests" are being fabricated for test in PBRF. These fuel pins which are encapsulated in a stainless steel capsule are designed to operate at an 1800°F (1255°K) T-111 clad temperature. Integrity of the fuel pins will be determined by the ability of the clad to resist fuel swelling and to contain fission gases. Two sizes of fuel pins are being fabricated for these proof tests. The prototype pins designated as "D" size (3/4" (1.91×10^{-2}M) diameter) will be used for true time tests and a "D/2" size (3/8" (9.53×10^{-3}M) diameter) which will be used for accelerated tests. Fuel burnup rates two to four times greater than true time tests can be achieved with these smaller pins. In addition, by reducing the clad thickness on some of the D/2 pins measurable clad swelling should be obtained. This contract included an initial phase for development of fabrication and assembly techniques, procedure qualifications, furnace cycling and compatibility tests, and fabrication of 5 prototype fuel pins. The final phase utilized this experience to fabricate the remainder of the capsules assemblies and fuel pins with minor modifications.

This report summarizes the details of hardware fabricated in this program with cross references to drawing modifications and assembly procedures. Capsule descriptions and drawings are presented along with a discussion of the salient features of fuel pin and capsule design. Implications of the design features as they affect fabrication requirements are also discussed. The major portion of the text is devoted to describing the results of the fabrication development and procedure qualification phase. In addition, detailed appendices are included to present all assembly sequences and welding and brazing procedures used in this program.

III. CAPSULE ASSEMBLY FABRICATION

A summary table of the hardware produced in this program and its disposition is given in Table 1. In this summary, the program phase identification refers to basic groupings called for in this program: Phase I, demonstration of fabrication techniques; Phase II, fabrication of capsule assemblies; and Phase III, fabrication of modified design fuel pins. Detail drawings of this hardware are given in Figures 1, 2 and 3. The drawing nomenclature is used in the discussions presented throughout this report.

The assembly design and fabrication techniques used for this hardware are described below. The design requirements dictate the requirements for fabrication and assembly. Hence, the design features are discussed first, followed by a discussion of the salient features of hardware fabrication, and finally by a description of the supporting process development and hardware qualification data.

Fuel Pin and Capsule Description

Basic capsule assemblies consisted of fuel pins of T-111 clad tungsten lined uranium mononitride encased in AISI 304 stainless steel capsule assemblies. Two basic fuel pin sizes were fabricated both with a 2-1/4 inch (5.72×10^{-2}M) fueled length. These are the D size, 3/4 inch (1.91×10^{-2}M) diameter fuel pin, and D/2 size, 3/8 inch (9.53×10^{-3}M) diameter pin. This grouping is further subdivided according to fuel cladding thickness into X and Y assemblies denoting respectively regular and thin clad designs. The grouping of assembly types is as follows:

X Assemblies

	NASA Dwg. No.	Clad OD	Clad Wall
D Size Fuel Pin	CD352463-1	.753" (1.91×10^{-2}M)	0.058" (1.50×10^{-3}M)
D/2 Size Fuel Pin	CD352462-1	.373" (9.49×10^{-3}M)	0.0265" (6.73×10^{-4}M)
D/2 Size Fuel Pin	CD352465-1	.373" (9.49×10^{-3}M)	0.0265" (6.73×10^{-4}M)

Y Assemblies

	NASA Dwg. No.	Clad OD	Clad Wall
D Size Fuel Pin	CD352463-1	.717" (1.82×10^{-2}M)	0.040" (1.02×10^{-3}M)
D/2 Size Fuel Pin	CD352462-1	.360" (9.15×10^{-3}M)	0.02" (5.08×10^{-4}M)
D/2 Size Fuel Pin	CD352465-1	.360" (9.15×10^{-3}M)	0.02" (5.08×10^{-4}M)

TABLE 1-1. HARDWARE DETAIL AND DISPOSITIONS SUMMARY

PHASE	FUEL PINS						CAPSULE ASSEMBLIES										
										Thermocouples (Fuel Center)							
	Size	Dwg. No.	Assem. Option	Special Modifications	Ident. No.	Disposition	Size	Dwg. No.	Assem. Option	Sheath Dia.	Wire Size	No. of Wires	Method of Attachment	Modification	Special Modifications	Ident. No.	Disposition
I	D/2	CD-352462-1 Mod. C-2	X	Depleted fuel rejected parts	D-0	Mounted and ground to center Del. to NASA											
I	D/2	CD-352462-1 Mod. C-2	X	Depleted fuel	D-1	Thermocycle test											
I	D	CD-352463-1 Mod. C-2	X	5 depleted fuel pellets; 1 enriched fuel pellet	D-2	Encapsulated 901-D2	D	CD-352463-1 Mod. C-2	X	3/32"	.016	4	Braze		Short TC lead wire	901-02	Delivered
I	D/2	CD-352462-1 Mod. C-2	X	Depleted fuel	D-3	Thermocycle test											
I	D/2	CD-352462-1 Mod. C-2	X	Depleted fuel	D-5	Thermocycle test											
I	D/2	CD-352462-1 Mod. C-2	X	4 depleted fuel pellets; 2 enriched fuel pellets	D-7	Encapsulated 901-D7	D/2	CD-352462-1 Mod. C-2	X	1/16"	.012	2	Braze		Short TC lead wire	901-07	Delivered
I	D	CD-352463-1 Mod. C-2	Y	Sealed at ~8 psia He.	504A	Encapsulated then destructively examined	D	CD-352463-1 Mod. C-2	Y	3/32"	.016	4	Braze	Hot end swaged to reduce wire to .013". No alumina tube over hot jnct.	Sealed at 8 psia	901-504A	Destructively examined
I	D	CD-352463-1 Mod. C-2	Y	Sealed at ~8 psia He.	504B	Encapsulated 901-504B, B-1	D	CD-352463-1 Mod. C-2	Y	3/32"	.016	4	Braze	Hot end swaged to reduce wire to .013". No alumina tube over hot jnct.	Sealed at ~14 psia	901-504B	Delivered then ret'd for re-encapsulation
							D	CD-352463-1 Mod. D-7	Y	3/32"	.016	4	Braze	Hot end swaged to reduce wire to .013". No alumina tube over hot jnct.	Re-encapsulated sealed at ~14 psia	901-504B1	Delivered
I	D/2	CD-352462-1 Mod. C-2	Y	Sealed at ~8 psia He.	503A	Encapsulated then removed & furnace tested	D/2	CD-352462-1 Mod. C-2	Y	1/16"	.012	2	Braze	Hot end swaged to reduce wire to .010".	Sealed at ~14 psia	901-503A	Delivered then returned
I	D/2	CD-352462-1 Mod. C-2	Y	Sealed at ~8 psia He.	503B	Encapsulated 901-503B1	D/2	CD-352462-1 Mod. D-8	Y	1/16"	.010	2	Braze		Sealed at ~14 psia	901-503B1	Delivered
I	D/2	CD-352462-1 Mod. C-2	Y	Sealed at ~8 psia He.	503C	Encapsulated 901-503C, C-1	D/2	CD-352462-1 Mod. C-2	Y	1/16"	.010	2	Braze		Re-encapsulated sealed at ~14 psia	901-503C1	Delivered
							D/2	CD-352462-1 Mod. D-8	Y	1/16"	.010	2					
II	D/2	CD-352462-1 Mod. E-1	X		501A	Encapsulated 901-501A	D/2	CD-352462-1 Mod. F-3	X	1/16"	.010	2	Braze			901-501A	Delivered
II	D/2	CD-352462-1 Mod. E-1	X		501B	Encapsulated 901-501B	D/2	CD-352462-1 Mod. F-3	X	1/16"	.010	2	Braze			901-501B	Delivered
II	D	CD-352463-1 Mod. E-3	X		502A	Encapsulated 901-502A	D	CD-352463-1 Mod. F-4	X	3/32"	.016	4	Braze	Hot end swaged to reduce wire size to .013".		901-502A	Delivered

TABLE 1-2. HARDWARE DETAIL AND DISPOSITIONS SUMMARY

PHASE	FUEL PINS					CAPSULE ASSEMBLIES										
									Thermocouples (Fuel Center)							
	Size	Dwg. No.	Assem. Option	Ident. No.	Disposition	Size	Dwg. No.	Assem. Option	Sheath Dia.	Wire Size	No. of Wires	Method of Attachment	Modification	Special Modifications	Ident. No.	Disposition
II	D/2	CD-352462-1 Mod. E-1	Y	503D	Encapsulated 901-503D	D/2	CD-352462-1 Mod. G-2	Y	1/16"	.010	2	Braze			901-503D	Delivered
II	D/2	CD-352462-1 Mod. E-1	Y	503E	Encapsulated 901-503E	D/2	CD-352462-1 Mod. G-2	Y	1/16"	.010	2	Braze			901-503E	Delivered
II	D/2	CD-352462-1 Mod. E-1	Y	503F	Encapsulated 901-503F	D/2	CD-352462-1 Mod. G-2	Y	1/16"	.010	2	Braze		.040 dia. gas tc brazed into bot. end cap	901-503F	Delivered, ret'd for re-encapsulation
II						D/2	CD-352462-1 Mod. H-1	Y	1/16"	.010	2	EB Weld		Re-encapsulated	901-503F1	Delivered
II	D/2	CD-352462-1 Mod. E-1	Y	503G	Encapsulated 901-503G	D/2	CD-352462-1 Mod. G-2 Accelerated Design	Y	1/16"	.010	2	Braze		.540 OD with .011 gap - .040 dia. gas tc brazed into bot. end cap	901-503G	Delivered
II	D/2	CD-352462-1 Mod. E-1	Y	503I	Encapsulated 901-503I	D/2	CD-352462-1 Mod. G-2 Accelerated Design	Y	1/16"	.010	2	Braze		.540 OD with .011 gap	901-503I	Delivered
II	D	CD-352462-1 Mod. E-3	Y	504C	Encapsulated 901-504C	D	CD-352462-1 Mod. G-1	Y	3/32"	.016	4	Braze	Hot end swaged to reduce wire to .013". No alumina tube over hot jnct.		901-504C	Delivered
II	D	CD-352462-1 Mod. E-3	Y	504E	Encapsulated 901-504E	D	CD-352462-1 Mod. G-1	Y	3/32"	.016 (Top) .013 (Bottom)	4	Braze	Top TC hot end swaged to reduce wire to .013. No alumina tube over hot jnct.		901-504E	Delivered
II	D/2	CD-352462-1 Mod. E-1	X	501C	Encapsulated 901-501C	D/2	CD-352462-1 Mod. H-1	X	1/16"	.010	2	EB Weld			901-501C	Delivered
II	D/2	CD-352462-1 Mod. E-1	X	501D	Encapsulated 901-501D	D/2	CD-352462-1 Mod. H-1	X	1/16"	.010	2	EB Weld			901-501D	Delivered
II	D/2	CD-352462-1 Mod. E-1	X	501E	Encapsulated 901-501E	D/2	CD-352462-1 Mod. H-1	X	1/16"	.010	2	EB Weld			901-501E	Delivered
II	D/2	CD-352462-1 Mod. E-1	X	501F	Encapsulated 901-501F	D/2	CD-352462-1 Mod. H-1	X	1/16"	.010	2	EB Weld			901-501F	Delivered
II	D	CD-352463-1 Mod. E-1	X	502B	Encapsulated 901-502B	D	CD-352463-1 Mod. H-1	X	1/8"	.020	2	EB Weld	Alumina tube placed over hot jnct.		901-502B	Delivered
II	D	CD-352463-1 Mod. E-1	X	502C	Encapsulated 901-502C	D	CD-352463-1 Mod. H-1	X	3/32"	.016 (Top) .013 (Bottom)	4	EB Weld	Top TC hot end swaged to reduce wire to .013. Alumina tube over top hot jnct. but not bottom		901-502C	Delivered
II	D/2	CD-352462-1 Mod. E-1	Y	503H	Encapsulated 901-503H	D/2	CD-352462-1 Mod. G-2	Y	1/16"	.010	2	Braze			901-503H	Encapsulation removed
						D/2	CD-352462-1 Mod. H-1	Y	1/16"	.010	2	EB Weld		Re-encapsulated	901-503H1	Delivered
II	D	CD-352462-1 Mod. E-1	Y	504D	Encapsulated 901-504D	D	CD-352463-1 Mod. G-1	Y	1/8"	.020	2	Braze			901-504D	Encapsulation removed

TABLE I-3. HARDWARE DETAIL AND DISPOSITIONS SUMMARY

PHASE	FUEL PINS						CAPSULE ASSEMBLIES										
										Thermocouples (Fuel Center)							
	Size	Dwg. No.	Assem. Option	Special Modifications	Ident. No.	Disposition	Size	Dwg. No.	Assem. Option	Sheath Dia.	Wire Size	No. of Wires	Method of Attachment	Modification	Special Modifications	Ident. No.	Disposition
II							D	CD-352463-1 Mod. H-1	Y	1/8"	.020	2	EB Weld	Alumina tube placed over hot jnct.	Re-encapsulated	901-504D1	Delivered
III	D/2	CD-352465-1 Mod. A-3	Y		505A	For Encapsulating under Contract NAS 3-14402											
III	D/2	CD-352465-1 Mod. A-3	Y		505B												
III	D/2	CD-352465-1 Mod. A-3	Y		505E												
III	D/2	CD-352465-1 Mod. A-3	Y		505F												
III	D/2	CD-352465-1 Mod. A-3	Y	W-Mo-Re Liner	509A												
III	D/2	CD-352465-1 Mod. A-3	Y	W-Mo-Re Liner	509B												
III	D/2	CD-352465-1 Mod. A-3	Y	W-Mo-Re Liner	509C												
III	D/2	CD-352465-1 Mod. A-3	Y	W-Mo-Re Liner	509D												
III	D/2	CD-352465-1 Mod. A-3	X		507A												
III	D/2	CD-352465-1 Mod. A-3	X		507B												
III	D/2	CD-352465-1 Mod. A-3	X		507C												
III	D/2	CD-352465-1 Mod. A-3	X		507D												

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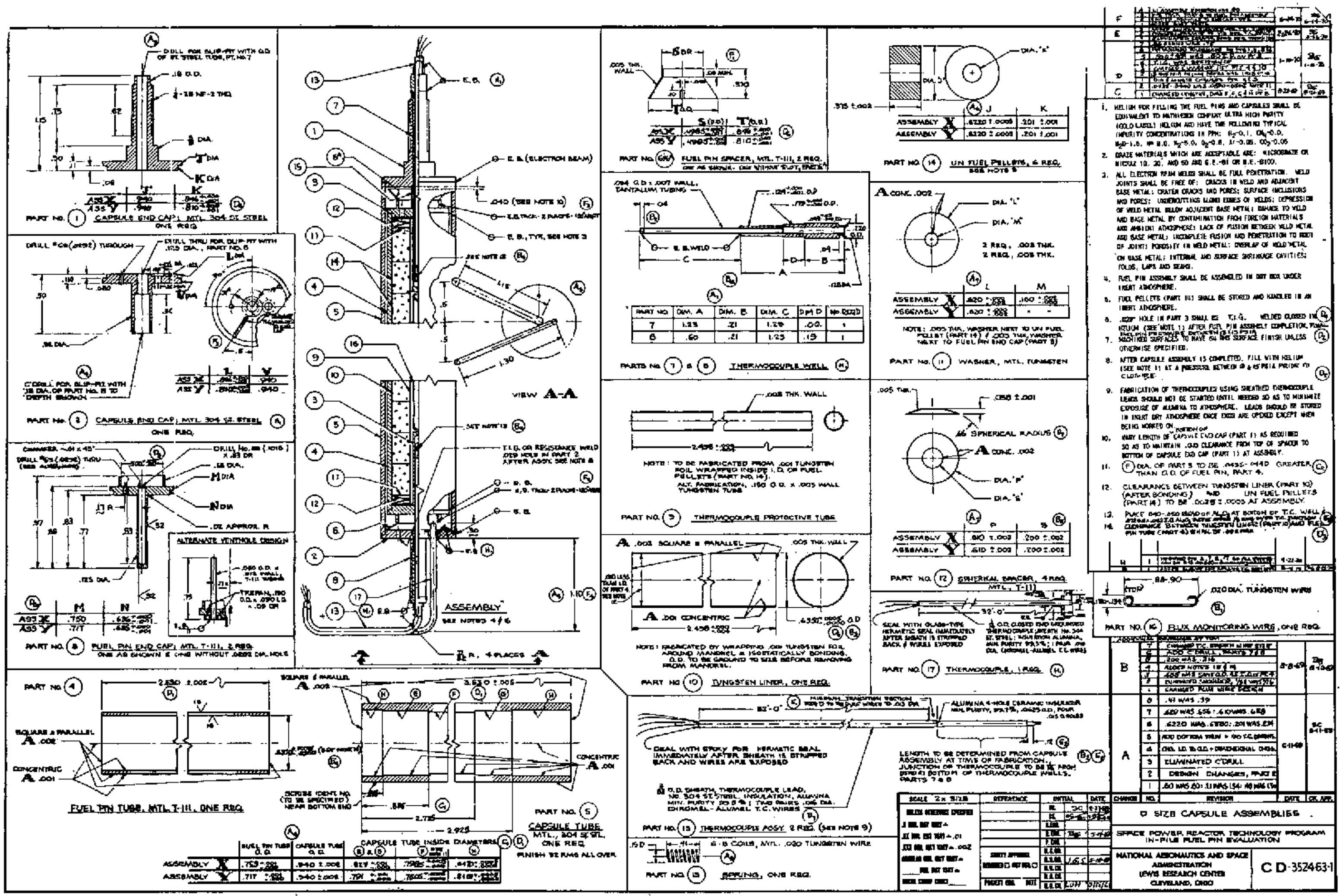
VIEW A-A
ASSEMBLY
D SIZE CAPSULE ASSEMBLIES
SPACE POWER REACTOR TECHNOLOGY PROGRAM IN-PILE FUEL PIN EVALUATION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
CLEVELAND, OHIO
CD-352463-1

Figure 1

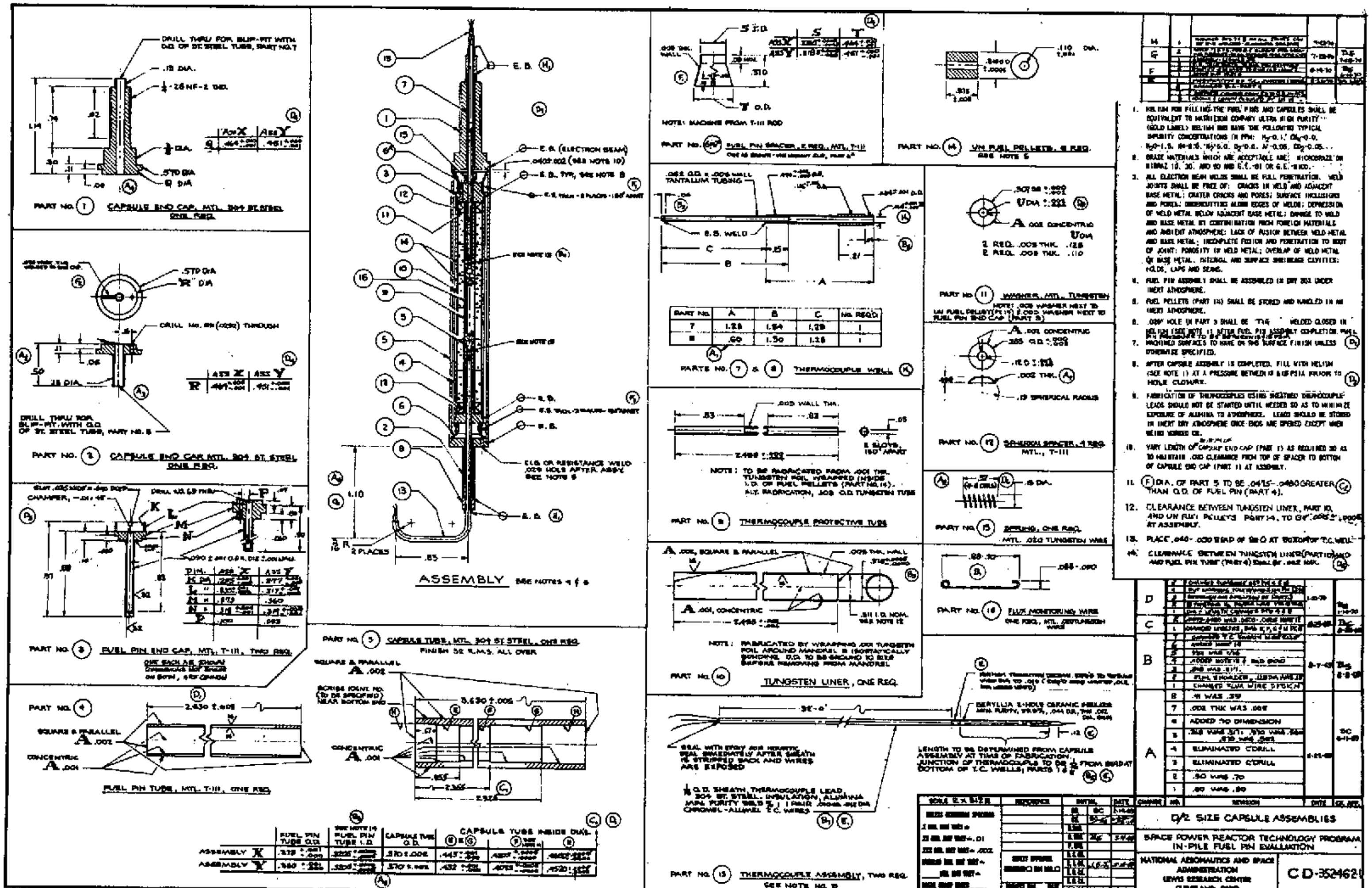
ASSEMBLY
TUNGSTEN LINER, ONE REQ.
1/2 SIZE CAPSULE ASSEMBLIES
SPACE POWER REACTOR TECHNOLOGY PROGRAM IN-PILE FUEL PIN EVALUATION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
CLEVELAND, OHIO
CD-352462

Figure 2

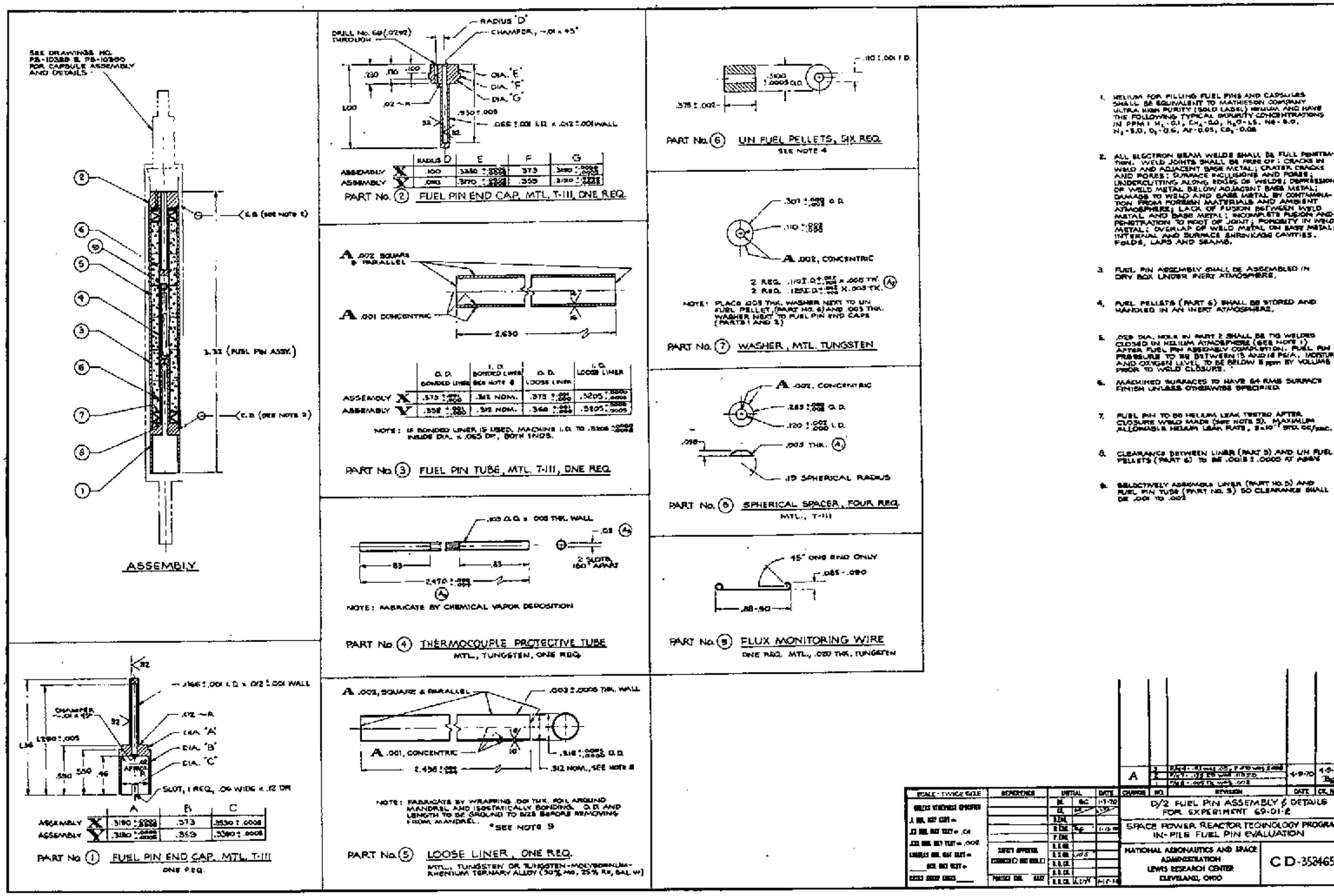
ASSEMBLY
PART No. 1 FUEL PIN END CAP, MTL. T-111
PART No. 2 FUEL PIN END CAP, MTL. T-111, ONE REQ.
PART No. 3 FUEL PIN TUBE, MTL. T-111, ONE REQ.
PART No. 4 THERMOCOUPLE PROTECTIVE TUBE
NOTE: FABRICATE BY CHEMICAL VAPOR DEPOSITION
PART No. 5 LOOSE LINER, ONE REQ.
PART No. 6 UN FUEL PELLETS, SIX REQ.
PART No. 7 WASHER, MTL. TUNGSTEN
PART No. 8 SPHERICAL SPACER, FOUR REQ.
PART No. 9 FLUX MONITORING WIRE
SPACE POWER REACTOR TECHNOLOGY PROGRAM
IN-PILE FUEL PIN EVALUATION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
CLEVELAND, OHIO
CD-352465-1

Figure 3

The latter group of fuel pins are of a modified design which are being encapsulated on a different contract, NAS 3-14402, as indicated also on Table I. The design of these assemblies is shown in the drawings of Figures 1 through 3. The fuel pin is equipped with axial thermocouple wells at each end. This complicates construction considerably but provides excellent temperature monitoring during testing.

Tungsten liners are used to prevent direct contact between the clad and UN fuel. To achieve this separation, both thermocouple well and cladding are isolated mechanically from the fuel with cylindrical tungsten liners and axial centering spacers. The thermocouple protective tube was produced by chemical vapor deposition from tungsten hexafloride while the liner was produced from foil by hot isostatic pressure welding. In several pins the liner was fabricated from the ternary W-30 Mo-25 Re (A/o) alloy rather than unalloyed tungsten to provide a more ductile liner. A tungsten neutron flux monitoring wire is positioned in the center of the fuel pin.

The fuel pin ends are equipped with centering spacers to achieve concentricity with the stainless steel capsule assembly. The capsule ID has a stepped configuration to achieve uniform fuel pin clad temperature. Both fuel pin and capsule are backfilled with ultrapure helium. The helium backfill, except for several early assemblies, was accomplished at ambient pressure and temperature.

Chromel alumel thermocouples are used for monitoring these capsules. Reliability was achieved by employing a simple design which readily accommodates severe axial temperature gradients and by employing stringent cleanliness standards in assembly.

Continuity of double encapsulation is maintained in the thermocouple assembly design. This requires a double well arrangement: one continuous with the fuel pin clad and one continuous with the stainless capsule. The capsule well contains a transition weld from stainless steel to tantalum to assure metallurgical compatibility at the mechanical interface between fuel pin TC well and capsule TC well. Details of this construction are described later.

An additional end cap thermocouple which operates at a considerably lower temperature is used on the D size pins for redundancy. In the event of failure of the center thermocouples the end cap thermocouple provides a reference temperature. This permits continuity of temperature monitoring once the relation between center and end cap temperature has been established. One D/2 size pin was also equipped with end cap couples. The center thermocouple in D size capsules were double ungrounded couples (four wires) with a common hot junction except for two D capsules which had single couples (see Appendix D).

Capsule Construction

Both fuel pin and capsule were constructed by electron beam welding. The full potential of electron beam welding was realized since components were designed specifically for this process. The only exceptions were gas tungsten arc vent hole welds required in both fuel pin and capsule. These were not structural welds since they were used only for helium backfilling to achieve design thermal performance. Conventional EB welding could not be used for sealing these holes since the beam would have to operate in helium rather than vacuum.

Electron beam welded construction proved to be advantageous throughout the capsule assemblies. The narrowness of EB welds (Figure 4) coupled with deep penetration permits use of minimum thickness end caps for both fuel pin and capsule. This characteristic minimizes total weld heat input thereby also minimizing weld distortion. Hence, weld joints could be designed for self alignment. This feature was essential in achieving concentricity of fuel pin and capsule and to assure alignment of thermocouple wells during assembly.

Electron beam welding of thermocouple assemblies permitted fabrication of these miniature subassemblies with great reproducibility. Joint strength and toughness was excellent. This is particularly important for the thermocouple well to thermocouple sheath weld which is subjected to considerable handling during bending of the leads and during capsule installation into the reactor.

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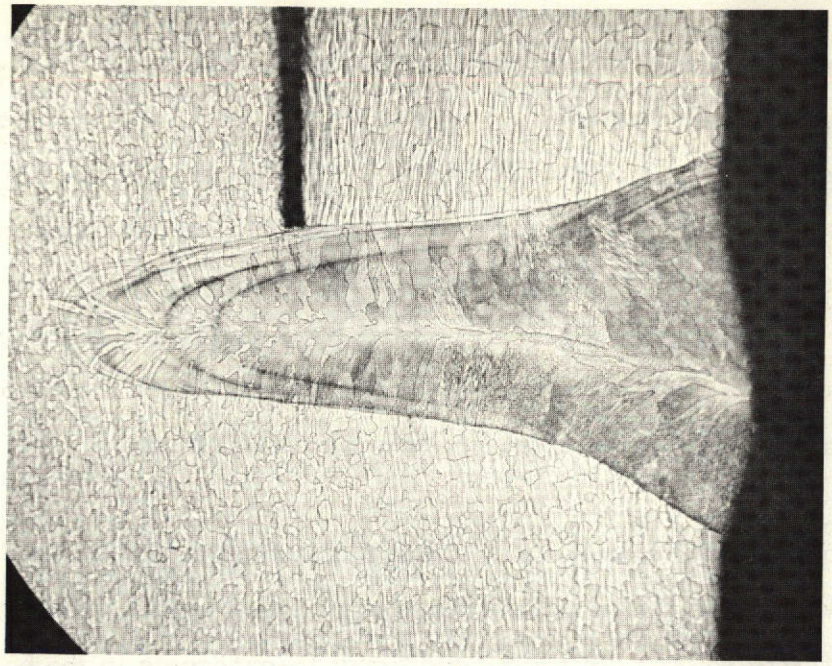

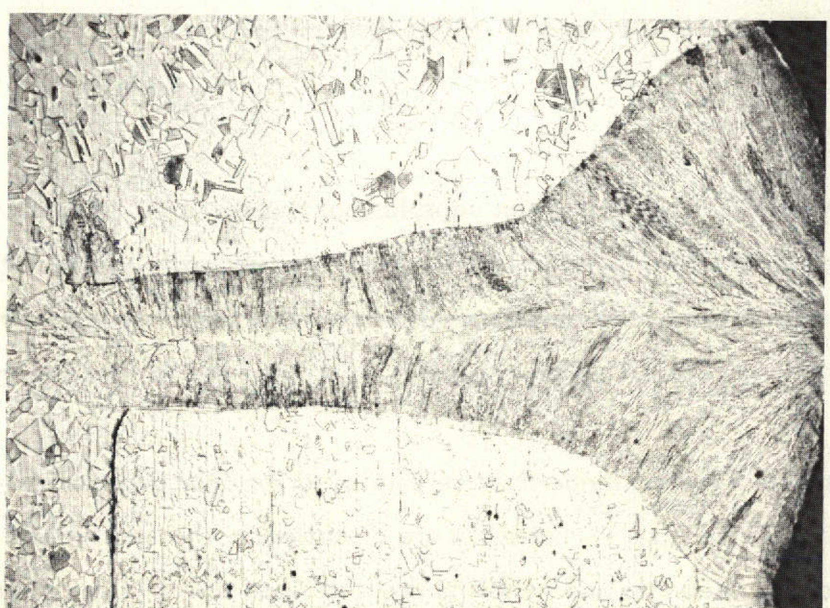

304 Stainless Steel Capsule, Welding Procedure 70336-7A

Figure 4. Electron Beam End Cap Weldments

The thermocouple well transition joint from tantalum well to stainless steel was produced as an EB lap joint with the stainless steel on the outside, Figure 5. Thermal strains are accommodated with the highest expansion alloy on the O.D. This puts the joint in compression. Residual compressive stresses are advantageous because stainless and tantalum form brittle intermetallics which are prone to failure under tensile loading. Again the small joint size achievable with EB welding minimizes this problem by minimizing alloying in the weld. In service this joint is located in a region within the capsule where the temperature never exceeds 500^{o}F so as to minimize thermal strains and cycling effects.

Each D/2 size capsule required seventeen welds, three of which are GTA welds, while the balance are EB welds. The D size capsule required nineteen welds. Two extra EB welds required for the D size capsule are for the additional thermocouple in the bottom end cap. Weld location and nomenclature is given in Figure 6. The salient features of producing each of the required joints, joint configuration and procedures employed are discussed later under Procedure Qualification and are listed in detail in Appendix I.

Capsule Assembly

The major subassemblies of the irradiation capsules are the fuel pins, thermocouples and capsules. The fuel pin and thermocouples were fabricated separately and mated during capsule assembly fabrication. The functional aspects of the assembly procedures are discussed in this text while detailed procedural data are summarized in Appendices.

Extremely stringent cleanliness standards were employed for component preparation and assembly. Handling precautions for assembly are discussed in this section while details of component fabrication, cleaning and handling are described under "Component Preparation and Handling" and in Appendices E, F, G and H.

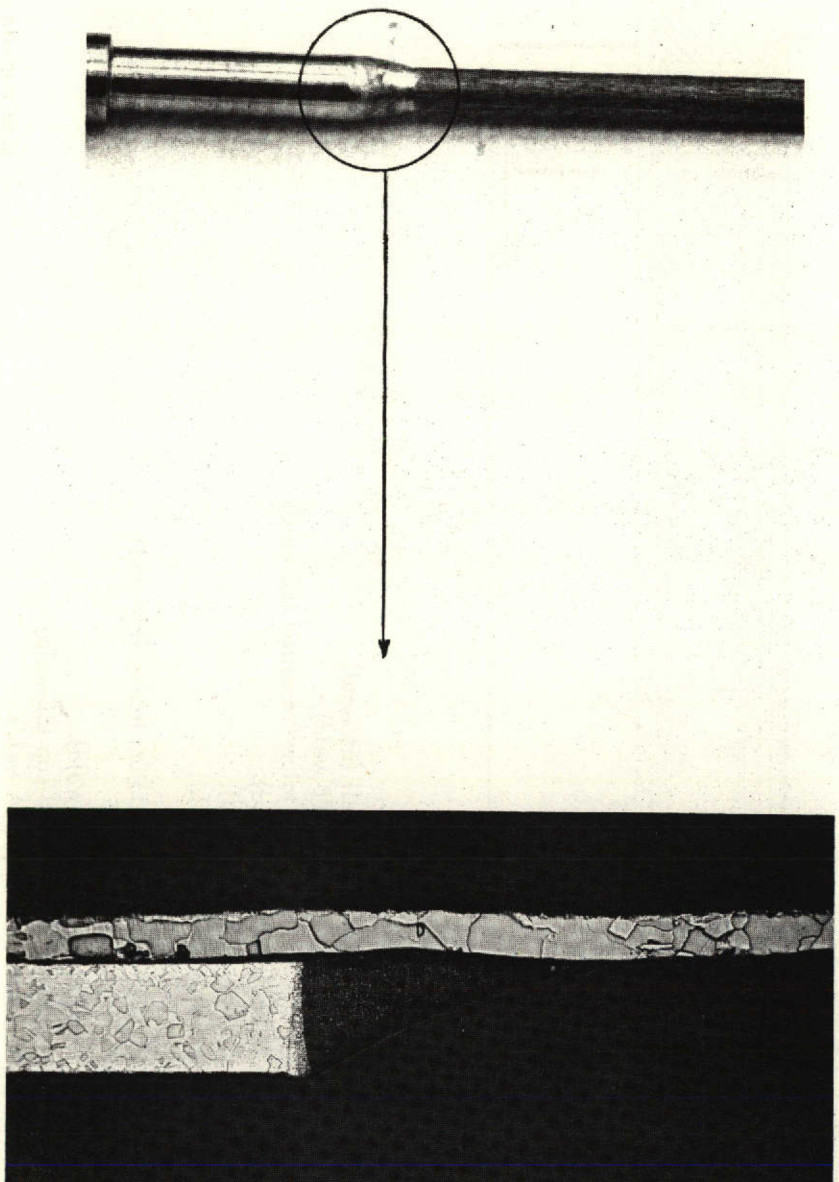

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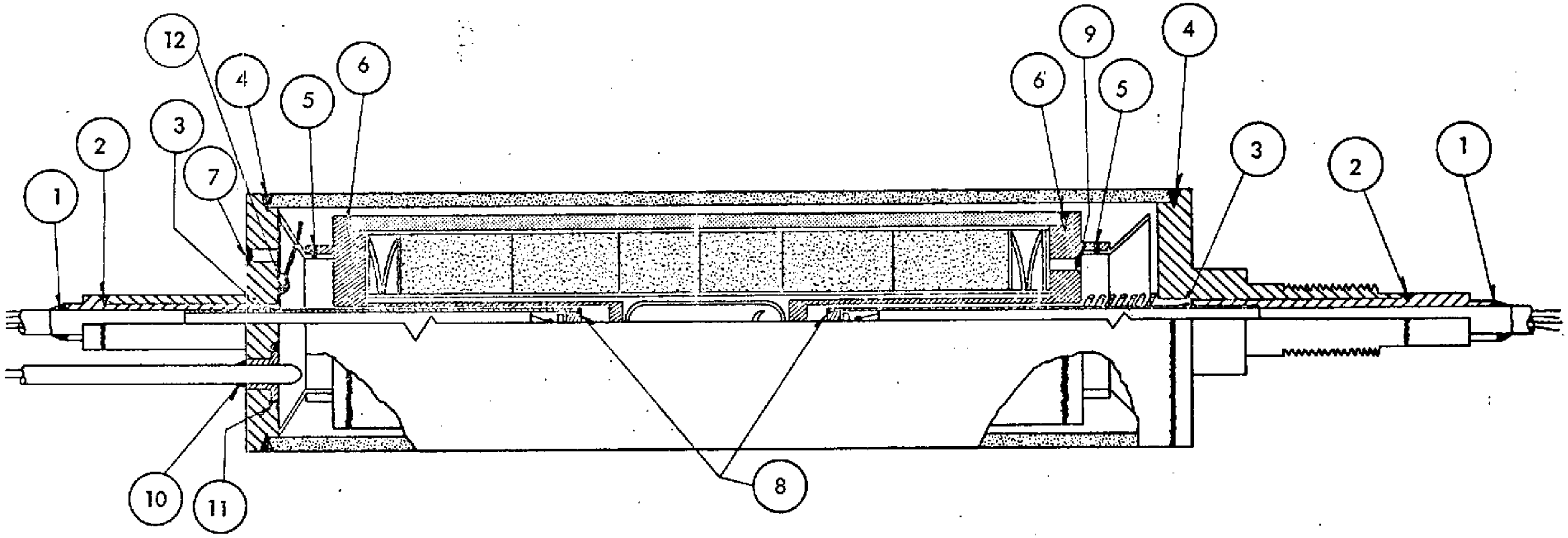
Figure 5. Electron Beam Welded Transition for Thermocouple Wells, Procedure 70336-3, Appendix I



1. Thermocouple sheath to thermocouple well (EB weld).
2. Thermocouple well to capsule end cap (EB weld).
3. Thermocouple well, stainless steel to tantalum transition (EB weld)
4. Capsule end cap to capsule tube (EB weld).
5. Fuel pin spacer to fuel pin (EB tack weld).
6. Fuel pin end cap to fuel pin tube (EB weld).
7. Capsule final closure (GTA weld).
8. Thermocouple well, tantalum plug to tantalum tubing (EB weld).
9. Fuel pin final closure (GTA weld).

*10. Gas thermocouple sheath to adaptor (EB weld).

*11. Gas thermocouple adaptor to capsule end cap (EB weld).

12. Positioning wire to capsule end cap (GTA weld).

* "D" size capsule only

Figure 6. Weld Schematic for Capsule Assemblies

Fuel Pin Fabrication

Assurance of cleanliness in fuel pin fabrication was achieved using "one stop" assembly within the electron beam weld chamber. "One stop" refers to the complete assembly and sealing of fuel pins without breaking to air at any time. To accomplish this a Sciaky welder chamber was modified for inert gas glove box operation. This permitted vacuum degassing of components and fuel at less than 10^{-5} torr (1.33×10^{-3} N/M^2) prior to assembly, and also provided an inert gas cover for fuel handling. Hence, the fuel, which was received in a sealed canister containing an inert gas cover, was never compromised by exposure to air. This approach has numerous advantages:

- It provided the cleanest possible environment for handling components.
- Cleanliness of components and contamination of fuel pellets was avoided in the event that difficulty was encountered since they could be stored indefinitely in sealed holding containers located within the weld chamber if opening the chamber became necessary.
- The weld assembly chamber was equipped with an inert gas monitoring system to assure compliance with high standards required for refractory metals. Ultrahigh purity helium was used throughout for fuel pin assembly.
- Only two lots of helium were used for this project. Hence, all handling and backfilling of fuel pins and capsules was accomplished with the fully qualified high purity helium under ideal monitored conditions.
- In all cases an overnight pumpdown (10^{-6} torr (1.33×10^{-4} N/M^2) range) was employed with heat lamp bakeout (~200°F (366°K)) to assure degassing of absorbed gases by both pin components and fuel. The overnight pumpdown was preceded by a short pumpdown and backfill of inert gas. During this backfill the fuel is removed from its shipping container to permit overnight degassing.

- By completing the assembly in one stop, the assembled fuel pin could be handled and inspected without severe handling restrictions. This stemmed from the fact that the fuel pin, once assembled and sealed, could be handled and then recleaned by chemical pickling and vacuum degassing just prior to encapsulation in the stainless steel capsule.

A typical set of fuel pin components prior to assembly are shown in Figure 7. Just prior to assembly all refractory metal components are pickled and degassed at 2400°F (1589°K) in a vacuum of 10^{-5} torr (1.33×10^{-3} N/M^2) for ten minutes. During these anneals the components are wrapped in tantalum foil for additional protection. The tungsten liner is pre-assembled into the fuel pin clad in air prior to fuel pin assembly. Otherwise, the fuel pins are assembled and welded within the EB weld chamber. Completed fuel pins are shown in Figure 8. These receive final inspection by helium leak test, x-ray and weld dye penetrant inspection. Prior to encapsulation they are cleaned, etched and annealed in a vacuum of less than 10^{-5} torr (1.33×10^{-3} N/M^2) for ten minutes at 2000°F (1366°K). The mechanical details of fuel pin assembly developed for this program are provided in the Pre-Irradiation Fuel Pin Data Record, Appendix A, and Fuel Pin Assembly Checkoff Record, Appendix C. These show precisely the steps followed in assembly as well as demonstrating the complete thoroughness with which each pin was documented in this program.

The welding laboratory facility where all assembly work in this program was accomplished is shown in Figure 9. The Sciaky welder is shown to the left. Figure 10 shows how this unit was modified with glove ports for the fuel pin assembly operation. This unit has a triode gun with 60 KV, 30 KW power supply and seam scanner. Pressures in the 10^{-6} torr (1.33×10^{-3} N/M^2) range are readily achieved.

The internal arrangement of the assembly chamber is shown ready for the assembly operation in Figure 11. All tooling and components are laid out conveniently for assembly. The work area and component holding surfaces are lined with tantalum foil to avoid any possibility of metallic contamination during assembly. Work tools used for handling components have

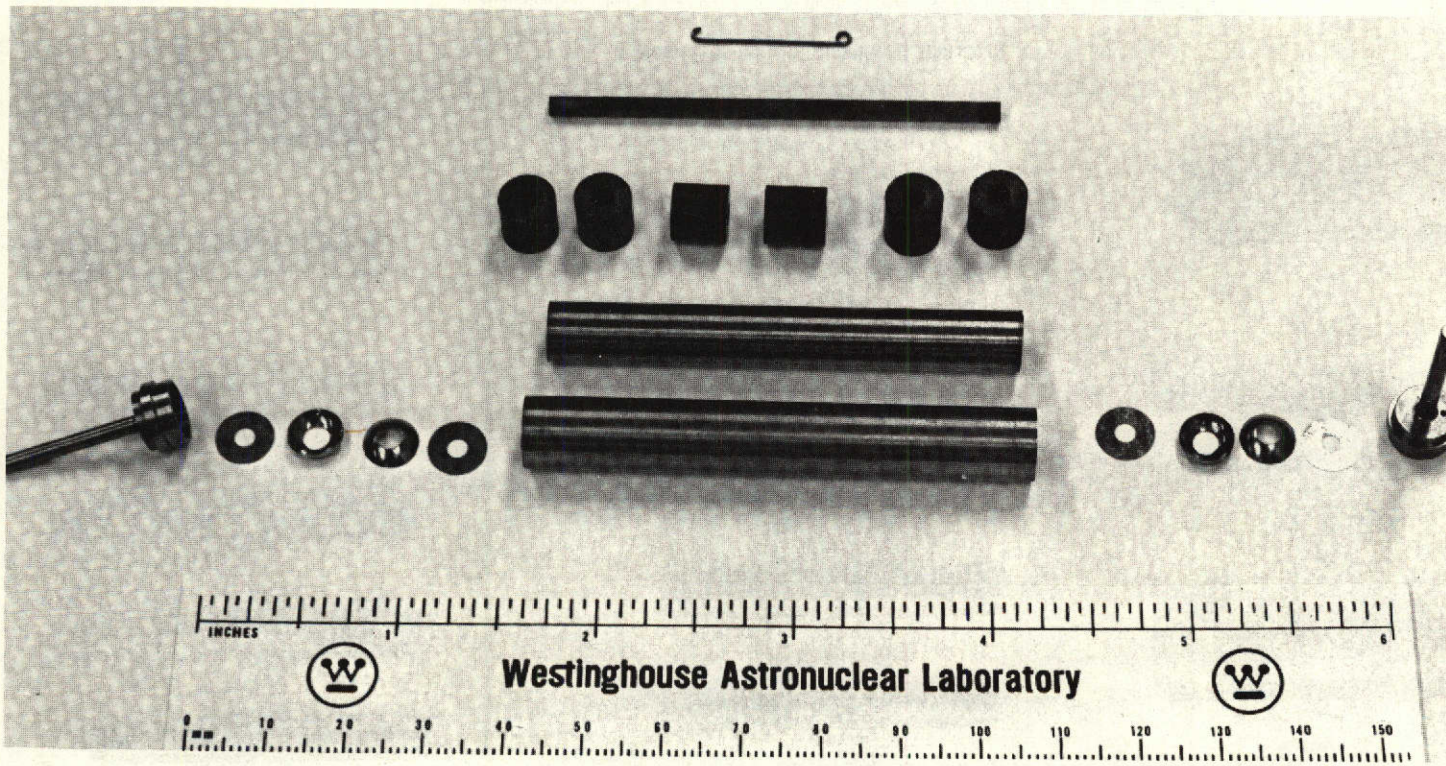


Figure 7. D/2 Size Fuel Pin Components

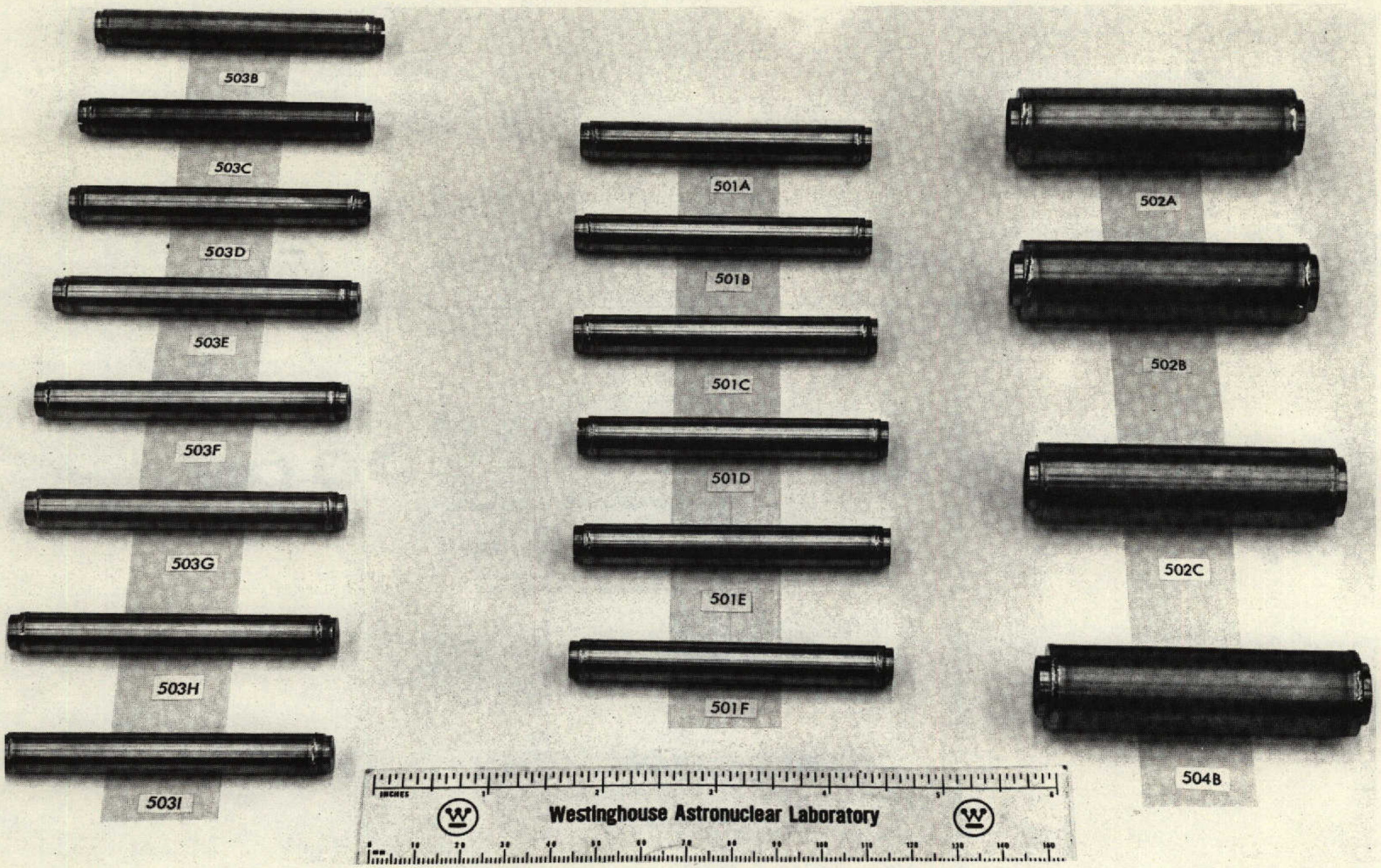


Figure 8. Completed Fuel Pins

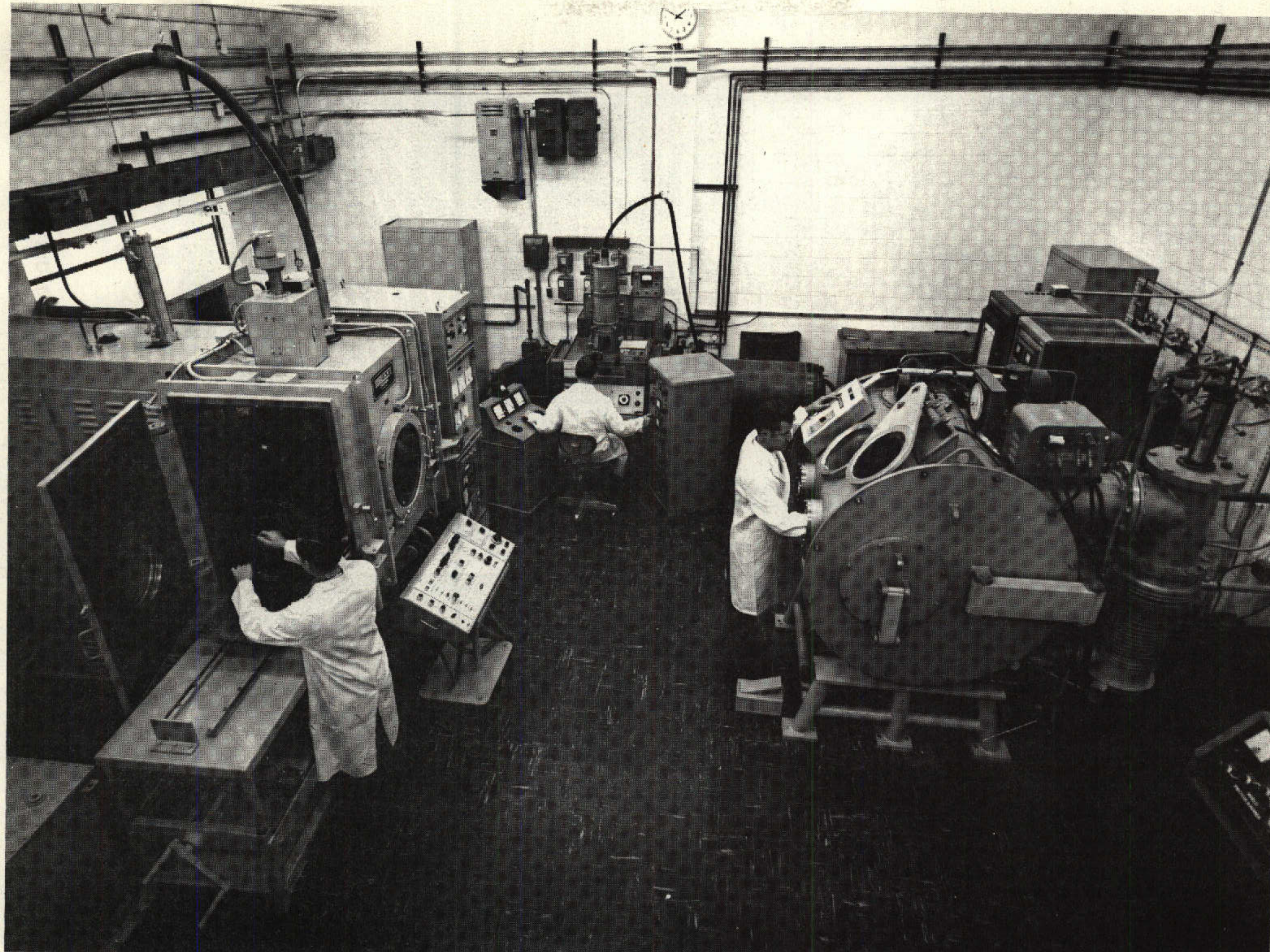


Figure 9. Welding Laboratory

Astronuclear Laboratory

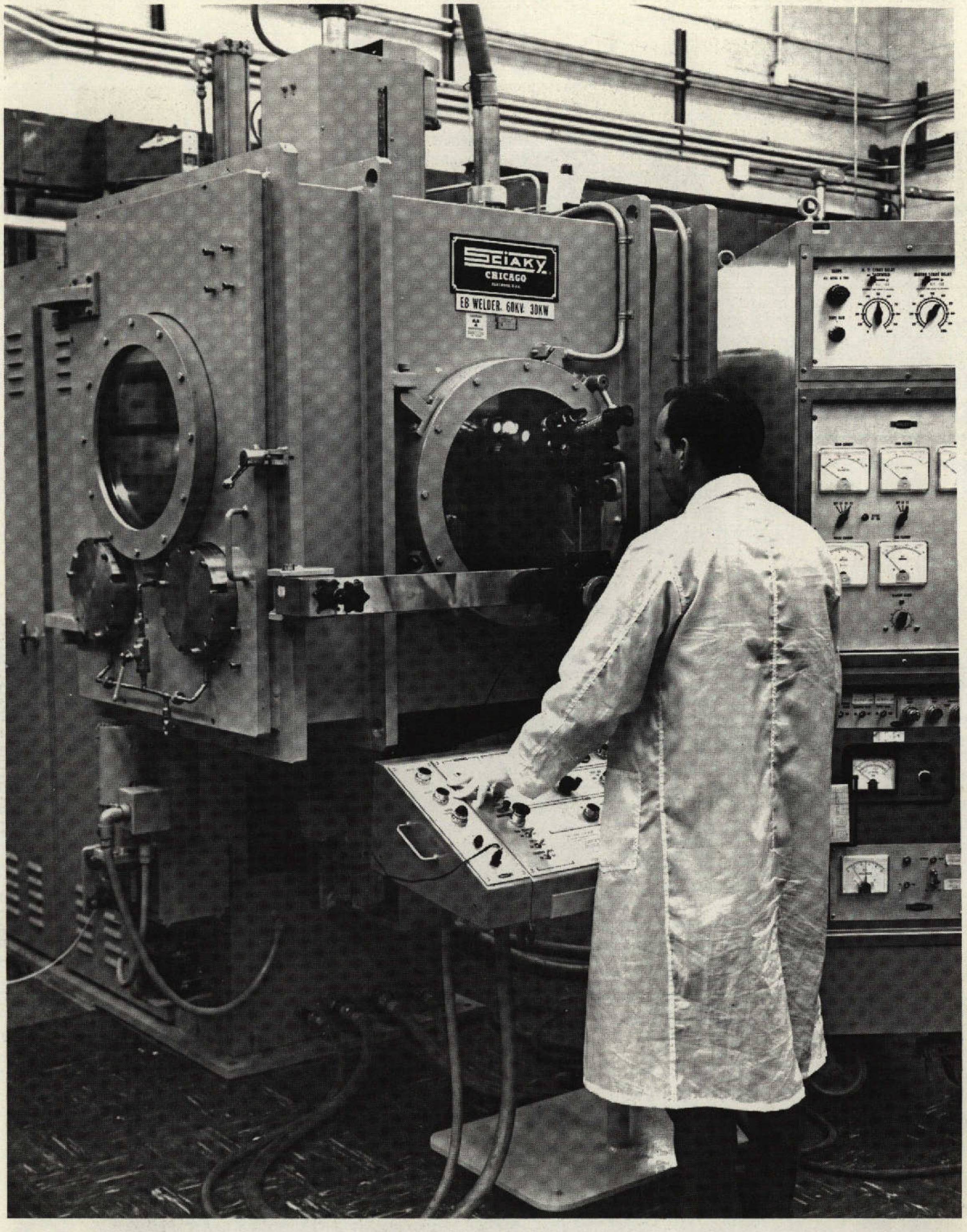


Figure 10. Sciaky Welding and Assembly Chamber External Arrangement

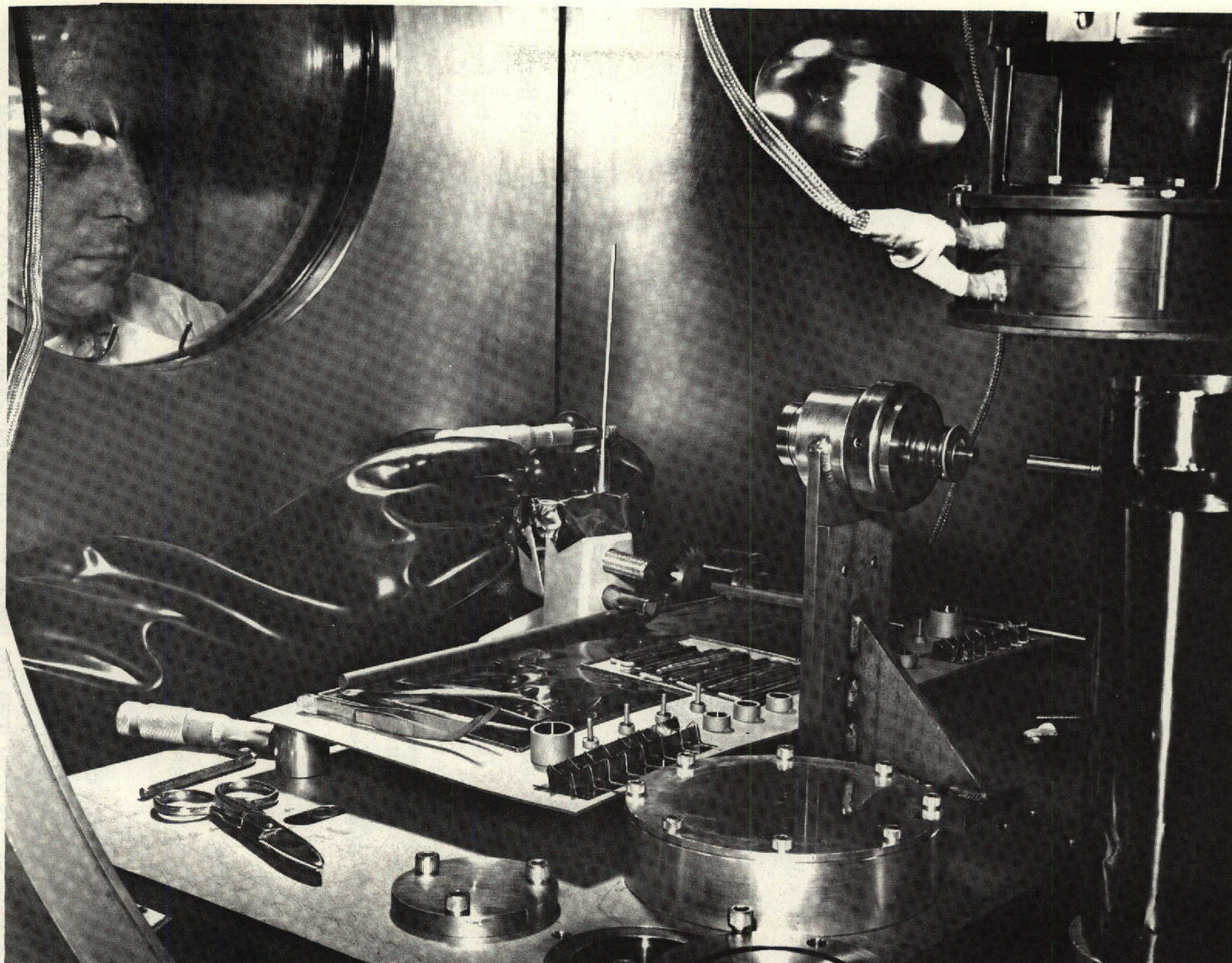


Figure 11. Fuel Pin Assembly Operation

been flame sprayed with alumina. Even though the chamber atmosphere is monitored for oxygen and moisture, a sample bottle is included should it be desirable to pull a gas sample for total impurity analysis. Moisture and oxygen levels were maintained below 5 ppm during assembly.

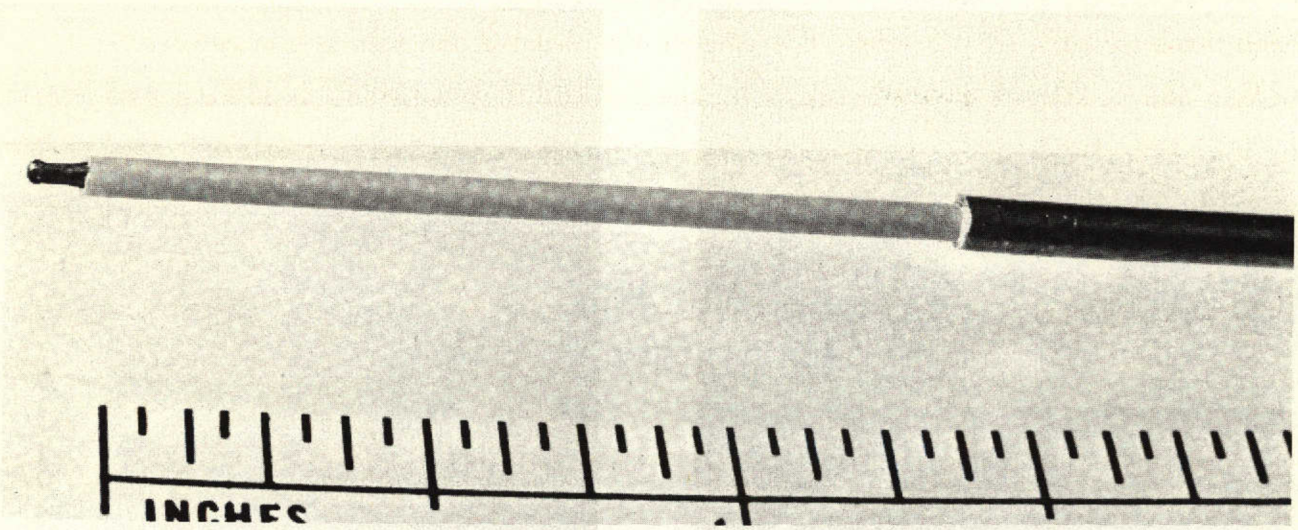
Thermocouple Fabrication

The important features of the thermocouple assemblies used in this program were:

- Electron beam welded construction.
- Utilization of a simple hot junction design.
- Hot junction preparation in a controlled humidity clean room.
- Pre-treatment of the hot junction by a 1400°F (1033°K) vacuum bakeout and high purity argon backfill prior to mating with the thermocouple well.
- Step by step inspection for continuity, resistivity and leak tightness.
- In situ calibration in completed capsules at 500°F (533°K) and 1000°F (811°K).

Hot junction preparation is shown in Figure 12, while a thermocouple well sub-assembly is shown in Figure 13. The thermocouple well to sheath joint is particularly critical since the sheath is only 0.008 inch (2.03×10^{-4} M) thick and the weld must not cause damage to the insulation. This joint is discussed further under Electron Beam Welding and the procedure presented in Appendix I. At this point in construction the thermocouple subassembly is mated to the capsule end cap. This sequence is best from a process reliability standpoint since thermocouple sub-assembly attachment to the end cap is more easily accomplished, the weld is more easily leak checked, and rework if required is considerably less than encountered in attaching the TC sub-assembly to an otherwise complete capsule. In this regard also, the capsule end cap weld is easily made with high reliability without any risk to thermocouple integrity.

On D size capsules which contain the extra end cap thermocouple a special adapter is utilized which permits this couple to be welded from the inside of the end cap, Welds No. 10 and 11, Figure 6. Welding from the inside with an axial beam orientation is necessary



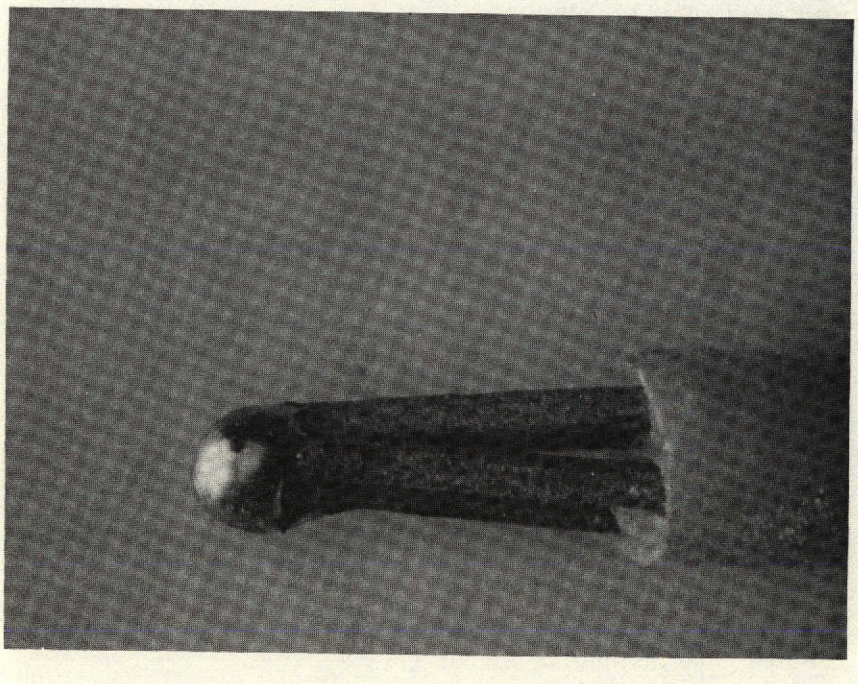


Figure 12. Four Wire D Size Hot Junction Thermocouple Construction

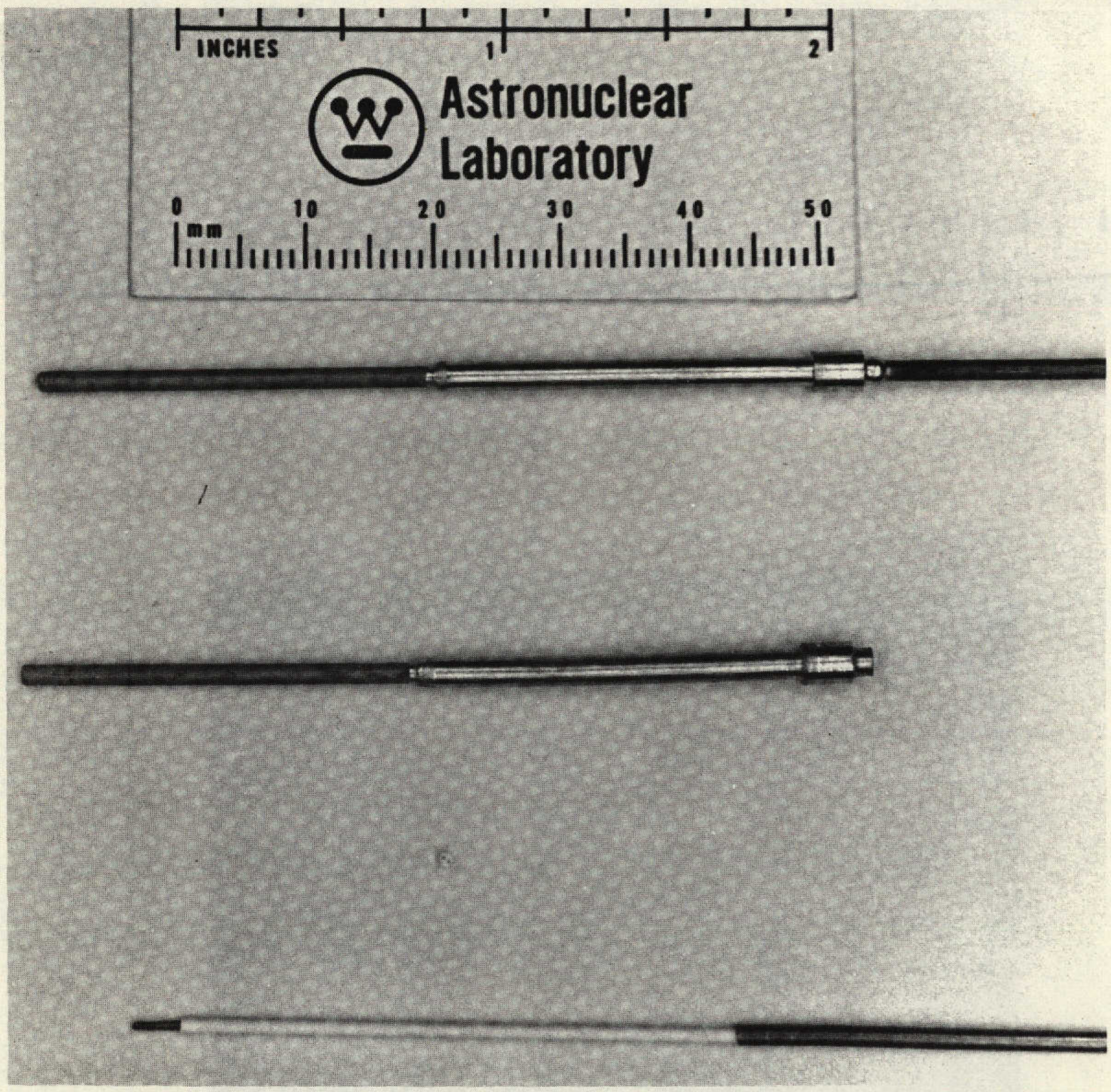


Figure 13. Thermocouple Subassembly Showing Attachment of Thermocouple Well to Sheath by EB Welding

since the thermocouple sheaths interfere if this couple were welded from the outside of the end cap. Details for this joint are given in Welding Procedure 70336-23, Appendix I.

The thermocouple hot junctions were constructed and checked according to details given in Appendix E. The thermocouple wells were fabricated as subassemblies and mated to the hot junction using welding procedures described in Appendix I. The subassembly sequence is given in Appendix B.

Final Capsule Assembly

Final capsule assembly consists basically of mating the fuel pins to capsules mechanically and in sealing the capsules with two electron beam end cap welds and one gas tungsten arc seal hole weld. Thermocouple subassemblies have already been mated to capsule end caps at this point of assembly. The detailed sequence for final assembly is given in Appendix D.

The fuel pin spacers are electron beam spot welded to the fuel pin to prevent cocking and maintain concentricity. One of these can be attached before insertion in the stainless clad. The other spacer must be attached to the fuel pin after it is inserted inside the capsule by protruding it out from the end of the capsule tube. This procedure is necessitated by the stepped inside diameter of the capsule tube coupled with the wide base diameter of the conical fuel pin spacer. Final axial clearance can be adjusted at this point if required by machining of the capsule end cap face.

To retain orientation of the fuel pin relative to the capsule a locking wire is welded to the bottom capsule end cap which mates with a notch in the bottom fuel pin spacer. Components are shown prior to assembly in Figures 14 and 15. A completed D size assembly is shown in Figure 16 and detailed welding procedures are given in Appendix I. Prior to capsule assembly the fuel pin and thermocouple assemblies have been fully inspected. In addition the fuel pin is recleaned by pickling and a 10 minutes at 2000°F (1366°K), 10^{-5} torr (1.33×10^{-3} N/M^2), vacuum degassing.

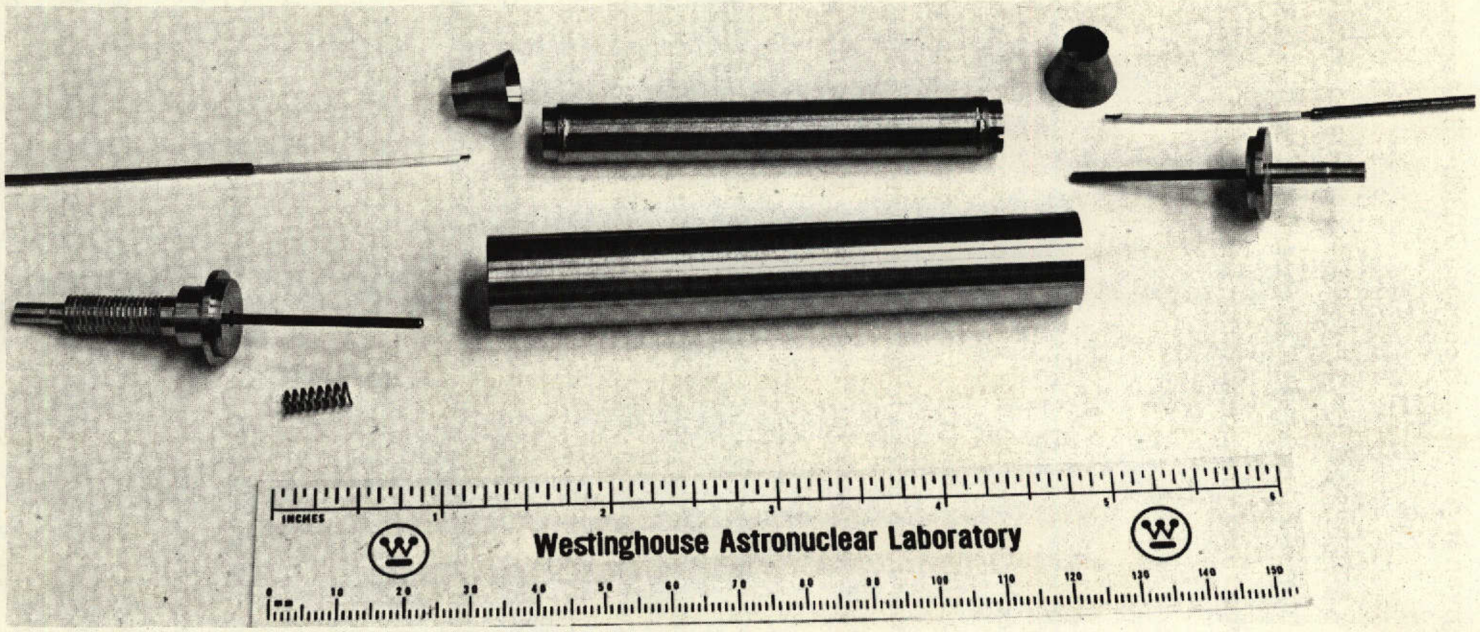


Figure 14. D/2 Size Fuel Pin and Capsule Ready for Final Assembly

Figure 15. D Size Fuel Pin and Capsule Ready for Final Assembly

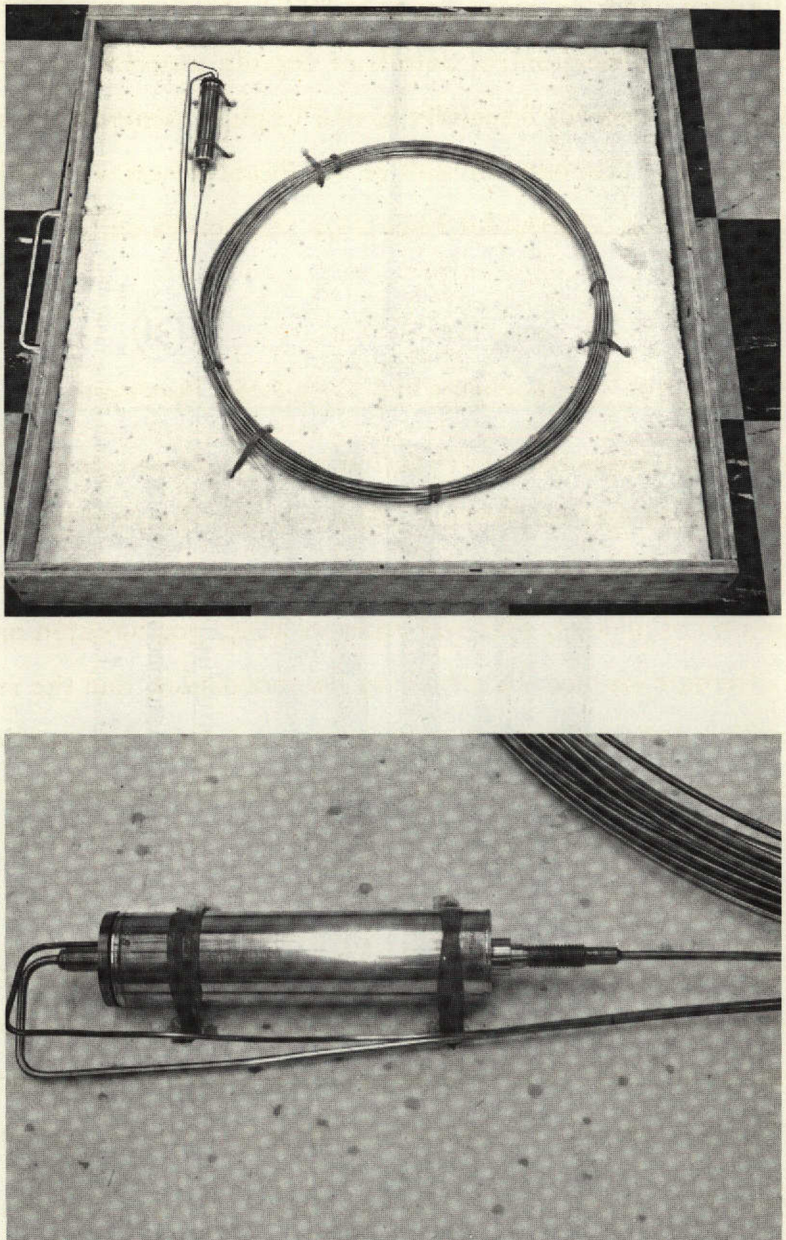


Figure 16. Completed D Size Capsule and Shipping Container

Following assembly the capsule is leak tested, dye penetrant inspected, x-rayed and checked out by heating in a furnace under an argon cover at 500°F (533°K) and 1000°F (811°K) for thermocouple calibration. The mechanical details of capsule assembly are provided in the Pre-Irradiation Capsule Data Record, Appendix B, and Capsule Assembly Checkoff, Appendix D. These show the exact assembly sequence as well as the thoroughness with which each capsule was documented in this program. Particular inspection procedures called for are given in Appendix F.

Development and Qualification of Procedures and Completed Hardware

This section of this report discusses the qualification tests conducted in this program. These tests were used to demonstrate that mechanical assembly, metallurgical procedures, and component fabrication techniques were satisfactory. The main categories investigated were the mechanical fit-up and alignment, electron beam welding, gas tungsten arc welding, use of brazing as an alternate method for attaching thermocouples, and the requirements for component preparation and handling. In addition, completed subassemblies and components were selectively evaluated by thermal exposure which included thermal cycling.

Mechanical Fit-up and Alignment

The mechanical design requirements of the fuel pin and capsule assembly were based almost completely on the desire to maintain axial, radial and rotational alignment and to control clearances. The assembly is designed to accommodate axial and radial expansion while maintaining concentricity. Assembly procedures and clearances were selected as follows:

- To minimize diametrial assembly gaps between fuel, liner and cladding for heat transfer.
- To maintain concentricity as closely as possible.
- To achieve the proper axial orientation between fuel, fuel pin and capsule.
- To provide adequate axial clearance for thermal expansion differences.

The particular aspects of the mechanical assembly related to these goals are as follows:

Diametrical Assembly Gaps

Very clean materials are more difficult to assemble when there is sliding contact such as the liner into the fuel pin tube because of loss of lubrication normally provided by oils, dirt or other foreign matter present even on parts that are supposedly clean. The extreme cleanliness of the fuel pin parts and very dry assembly atmosphere maintained in this program required an investigation to determine the minimum slip fit clearance for assembly. Fit up tests were conducted on T-111 and tungsten materials sized and cleaned identically to the fuel pin parts and it was concluded that a diametrical clearance of $.0015 {}^{+\,.0005}_{-\,.0000}$ ($2.92^{+.127}_{-.000} \times 10^{-5}$M) was necessary to assure that assembly could be made. This was a minimum requirement for both sized fuel pins for clearance between clad and liner.

Concentricity

Concentricity between the fuel pin and capsule was maintained by the fuel pin spacer. Tolerances had to allow for deviations in machining the fuel pin spacer OD and the capsule ID and assure concentricity while allowing sliding to occur due to movement caused by thermal expansion and contraction. Dimensions are specified on applicable drawings.

Axial Orientation Between Fuel, Fuel Pin and Capsule

Axial orientation of the fuel within the fuel pin was accomplished with spherical spacers (Belleville Springs) and flat washers. The total stack length of fuel, spacers and washers of each fuel pin was measured and compared to the internal length of each fuel pin. Adjustment was made to the number of flat washers inserted so that after welding (weld shrinkage averaged .007" (1.78×10^{-5} M) per fuel pin total for both welds) the spherical spacers were under slight compression. The fuel pin was positioned axially within the capsule by the fuel pin spacers. The fuel pin was also prevented from rotating within the capsule by meshing of a wire attached to the bottom end cap with a slot in the bottom fuel pin spacer. This prevented rotation of the fuel pin within the capsule due to vibrations or other movement.

Axial Clearance for Thermal Expansion

Thermal expansion was accommodated within the fuel pin by the spring effect of the spherical spacers and within the capsule by a .040" (1.02×10^{-3} M) gap between the end of the fuel pin spacer and the capsule end cap. At assembly this gap was measured and corrected if necessary by machining either the bottom or the shoulder of the top end cap.

Electron Beam Welding

Twenty-four separate welding procedures were developed for electron beam welding fuel pins and capsules in this program. These are given in Appendix I along with a cross reference list indicating on which specific capsules each procedure was utilized. Procedures were developed for welding in either a 2KW, 150 KV Hamilton Ziess unit or 30 KW, 60 KV Sciaky unit depending on specific component and assembly requirements.

Fairly conventional welding procedures were ultimately employed for most weldments while holding and alignment fixtures were kept as simple as possible. Naturally the rotating fixtures became more complex as assembly progressed and final end cap welds were made with thermocouples already in place. A typical fixturing arrangement for final end cap welding is shown in Figure 17.

A unique process was developed for attachment of the thermocouple well to thermocouple sheath. These welds were produced in accordance with procedures 70336-21 and 70336-22. The welding cycle was manually controlled using filament current, and the joint was traversed axially under manual control, while rotating under the beam. Excellent and consistent results were achieved.

Procedure requalifications was required for several weldments during the program as a result of converting the Sciaky welding gun from a diode to triode unit. These are indicated on applicable procedures and cross reference lists for various assemblies.

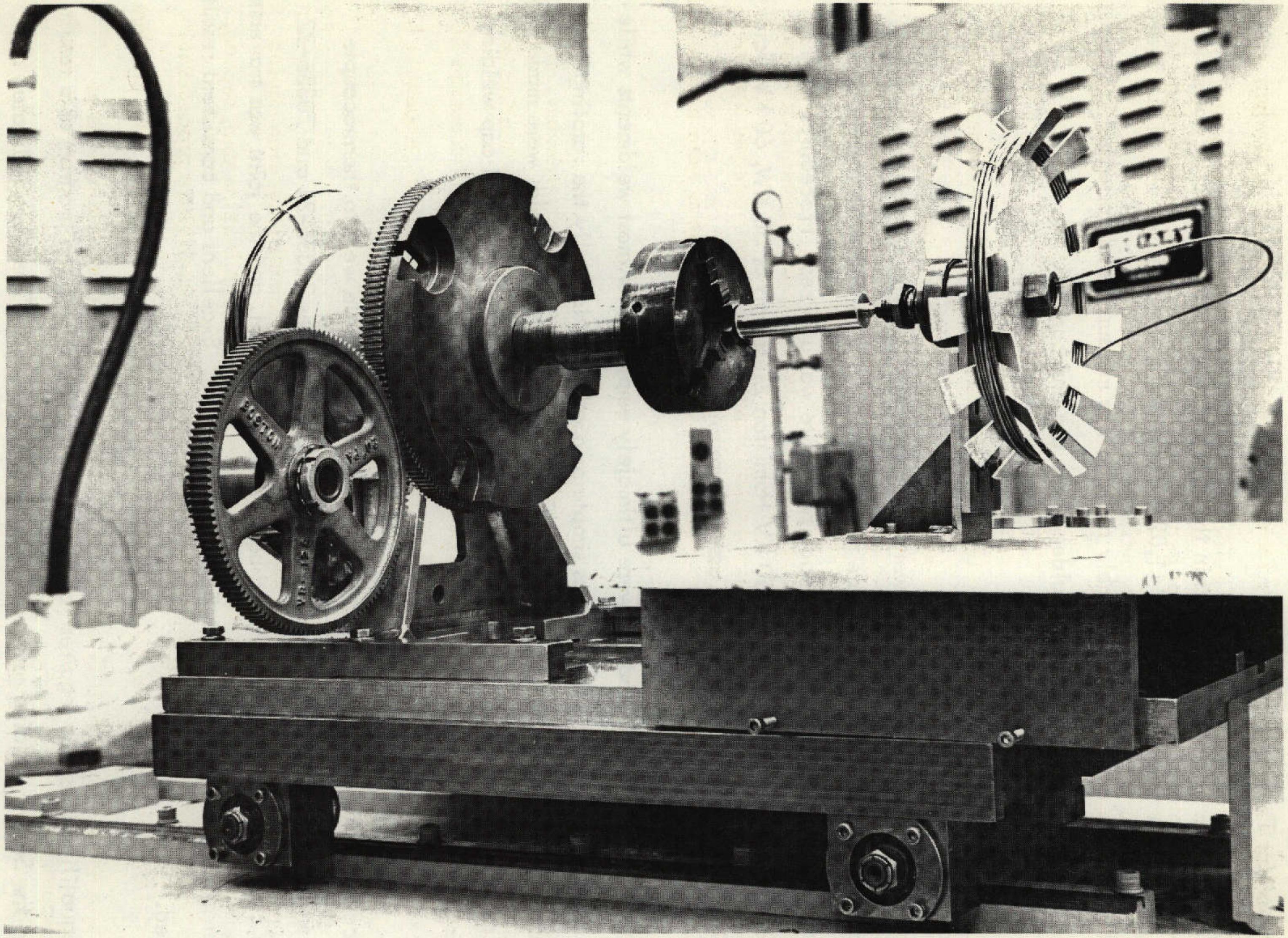


Figure 17. Fixture for Welding End Caps to Capsules With Thermocouples Attached

Weld requalification also became necessary for end cap welds in D size fuel pins when radiography indicated the presence of root defects. Since such defects occur frequently in blind electron beam welds this problem is of general interest. Hence, the analysis and resolution of this problem in this program is included as Appendix K.

Brazing

Although electron beam welding is used to attach the thermocouple sheath to thermocouple well and capsule end cap, brazing with various joint configurations was used in early assemblies. High quality capsules were produced using brazing. However, inability to consistently achieve a good brazed joint on the first attempt required rebrazing which was only marginally successful. Hence, leaking braze joints often resulted in prohibitive rework of capsule assemblies. In addition, the inherent brittleness of braze joints required special fixturing and very careful handling in subsequent operations. These problems were eliminated by using EB welding.

Only Nicrobraze 50 was evaluated since this was the only alloy NASA recommended. The brazing fixture used for producing these joints is shown in Figure 18. Induction heating is used. The actual joint is first vacuum purged and then brazed in argon. The Nicrobraze 50 was preplaced at the joint. The microstructures achieved in joint qualification, Appendix I, were entirely satisfactory.

In production of actual hardware two problems developed: first, thermal expansion caused axial movements of capsule relative to the thermocouple sheath during brazing and, second, leaks occurred frequently. These problems were not entirely interrelated since procedural resolution of the expansion problem did not alleviate the occurrence of leakers. The problem of leaks was approached procedurally and by utilizing different joint configurations as described in Appendix J.

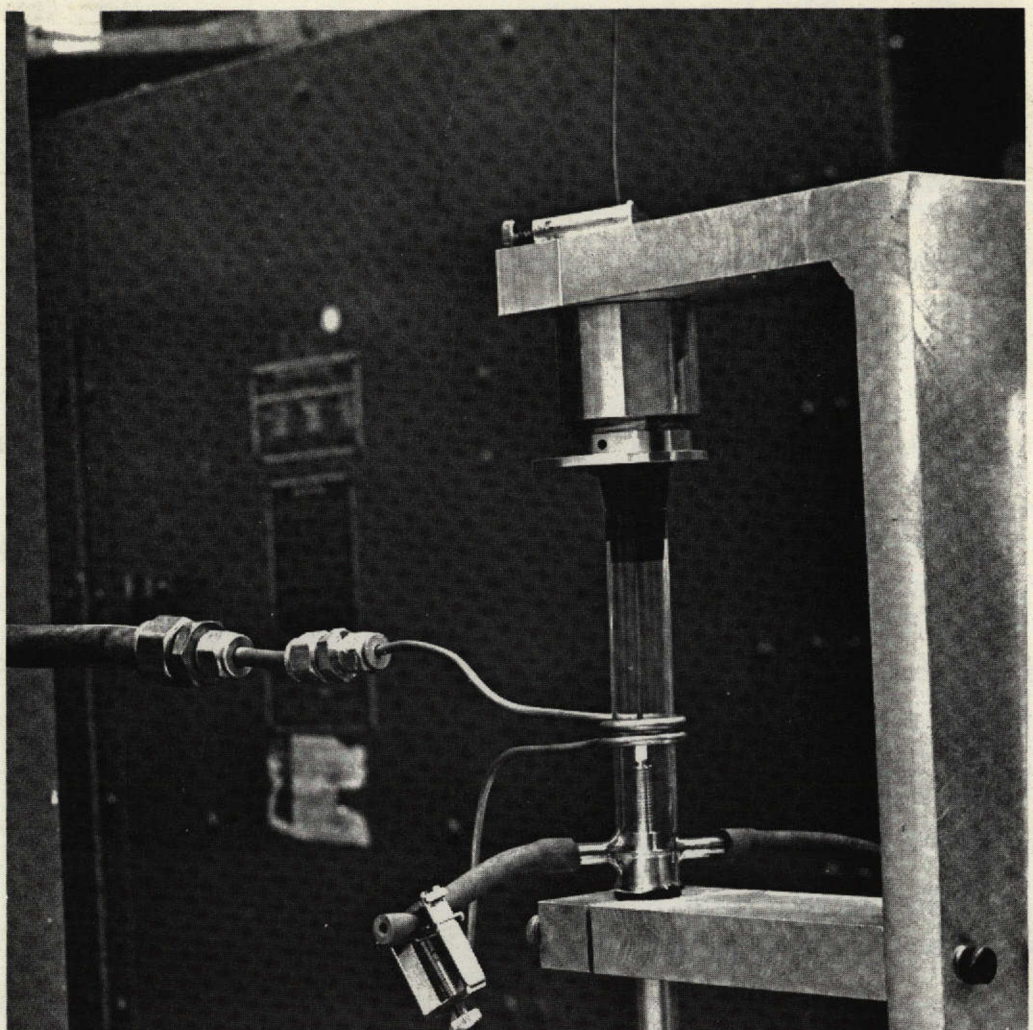


Figure 18. Vacuum/Inert Gas Purged Induction Heated Fixture for Brazing Thermocouples into Capsules.

Gas Tungsten Arc Welding

Gas tungsten arc welding was used only for seal welding vent holes in fuel pins and capsules. This permitted the use of electron beam welding for all structural assembly operations while still providing for helium backfill of the fuel pin and capsule assembly.

The earlier capsules in the program were sealed at a partial pressure of helium to reduce the pressure within the capsule and fuel pin at operating temperature. This was accomplished with reasonable success by two methods. The first utilized a partial pressure chamber atmosphere during sealing. To do this a T-111 electrode was shorted against the seal hole and burned off at the top to produce the seal weld in the T-111 fuel pin. This was accomplished with some risk of fuel pin damage as the electrode burned off and glow discharge occurred.

An alternate method proved to be more controllable but time consuming. In the alternate method the hole was sealed while the capsule was held at 600°F (589°K). The desired partial pressure would be achieved upon cooling to room temperature. This proved to be quite reliable. It was later decided that reduced pressure was unnecessary and in all but three pins backfilling was accomplished at one atmosphere helium. Modest changes in the fuel pin design were incorporated to achieve an adequate seal following the original procedure development. Final sealing procedures are given in Appendix I.

The fuel pin seal weld as originally qualified for welding at a partial pressure failed in thermal cycling tests. These failures appeared similar to high temperature failures previously observed at Westinghouse in making multipass plate welds in T-111. As a consequence this procedure was changed for the balance of the fuel pins and requalified by thermal cycling. The final procedures adopted utilized a fixed electrode, a short fixed welding cycle with taper control to eliminate cratering, and a filler wire preplaced in the seal hole. Details of the welding procedures are given in procedures 70336-13 and 70336-14 while the thermal cycling results are discussed under Assembly Qualification Testing.

Component Preparation and Handling

The important features or component preparation and handling utilized in this program from raw material to finished product are as follows:

- Raw material was characterized by specification, heat number, destructive and NDT inspection per Appendix G.
- Disposition records of various lots of material to finished capsule assemblies were maintained. Cross reference also in Appendix G.
- Uniform cleaning procedures were used throughout, Appendix H.
- All refractory metal components were degassed at 2400°F (1589°K) at a vacuum of 5 x 10^{-5} torr (6.66×10^{-3} N/M^2) or better for 10 minutes prior to assembly.
- Clean room handling procedures were used throughout as well as "one stop" fuel pin weld box assembly.
- Conventional machining practices were observed in preparation of components.

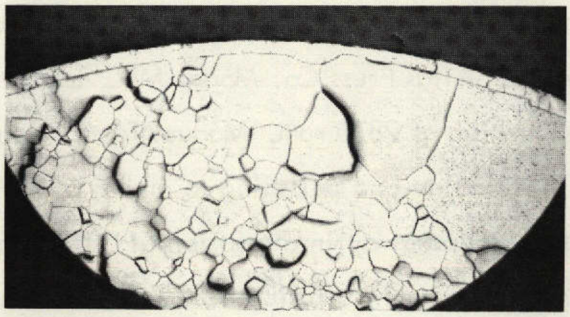
Machining of T-111 alloy parts was accomplished using high speed steel or carbide tools with large relief and top rake angles. Single point turning tools were ground to 10° back rake, 5° side rake, 5° side clearance, 45° trail angle and 0.020" (5.08×10^{-4} M) nose radius. Tap magic lubricant was used as a cutting compound to reduce the tendency to tear or gall which is characteristic of all tantalum base alloys. Cutting speeds of 50-60 SFPM with roughing feeds or 0.008-0.012 ipr (2.03-3.04×10^{-4} MPR) and finishing feeds of 0.005-0.006 ipr (1.27-1.52×10^{-4} MPR) were used. Honing with diamond honing stones was utilized to produce a surface finish of 16 rms or better on the ID of the fuel pin tubes. Specialized handling other than indicated above was required for the thermocouples, as described in Appendix E, and for fuel pin liners and thermocouple protective tubes.

The fuel pin liners were used as a diffusion barrier between the UN fuel and T-111 cladding. NASA-Lewis fabricated these liners from tungsten or tungsten-molybdenum-rhenium ternary alloy by wrapping .001" (2.54×10^{-5} M) thick foil between a molybdenum mandrel and tube followed by welding end caps to the tube and hot isostatic pressure welding to obtain a bond between the layers of foil. The molybdenum tubes were leached off and the liners centerless ground to size on the mandrel and delivered to Westinghouse Astronuclear Laboratory. Receiving inspection included visual examination and OD measurements at the center and near each end at 0^{o} and 90^{o}. Liners were cut to length by selecting the best area from the base piece, cutting ~.030" (7.12×10^{-4} M) overlength with an Atlas Press Co. Model MFC machine with a 4.0" diameter silicon-carbide cut off wheel turning at 2870 rpm. Manual feed was utilized at ~1.5 IPH. The ends were then squared by grinding and polishing to arrive at the correct length. The molybdenum mandrel was then leached away in a solution of 50% nitric acid and 50% water by volume periodically adding just enough sulfuric acid (3-5%) to keep a visible reaction going. The time required to completely dissolve the molybdenum mandrel was 24 to 48 hours. It was necessary to drill a hole 1/8" (3.18×10^{-3} M) diameter through the center of the mandrel for the tungsten-molybdenum-rhenium liners so that mandrel would be leached away at a much faster rate (2 to 4 hours) to prevent damage to the liner.

After etching, the liners were visually inspected and ID measured with precision plug gages. The OD was measured while the largest "go" plug gage was inserted to test for deformation caused by an ID protrusion present at the seam to a varying degree in most of the liners. Figure 19 shows photomicrographs of a typical protrusion.

The liners were x-rayed and dye penetrant inspected. Based on all of the above inspection including the size of the ID protrusion the liner was either selected for assembly or rejected. Identity of individual liners was maintained throughout processing.

Tungsten thermocouple protective tubes were fabricated by chemical vapor deposition utilizing the hydrogen reduction of gaseous WF_6. Deposition occurred on closely sized molybdenum mandrels which were heated to $600^{o}C$. Tubes were visually and dimensionally inspected, cut to length and slots were then electrical discharge machined through the tungsten deposit on D/2 size tubes in accordance with NASA Dwg. CD-352462-1 and CD-352465-1. The



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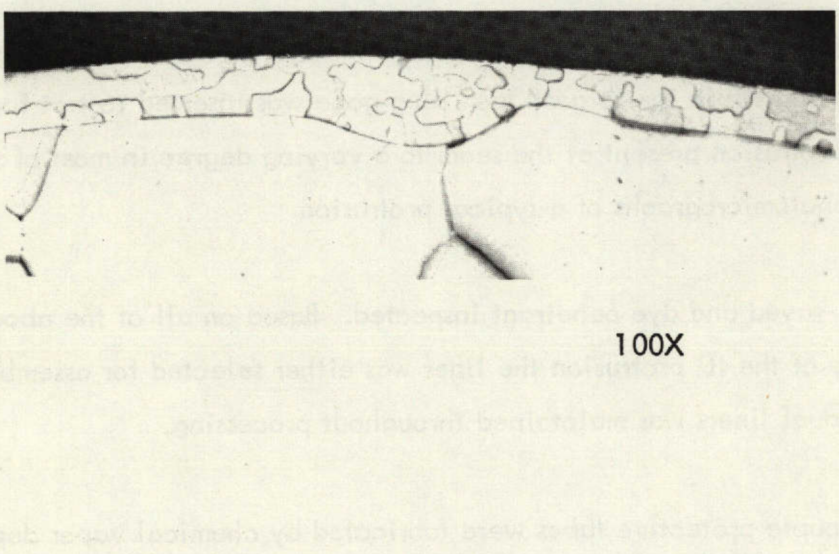

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Figure 19. Typical ID Protrusion of Tungsten Liner on Molybdenum Mandrel Formed in the Hot Isostatic Pressure Welding Process.

mandrel was etched with the same acid solution used for the loose liners above, nominally 50% nitric acid - 50% water by volume adding 3-5% sulfuric acid as necessary to keep the reaction going. After dissolving the mandrel the tubes were visually inspected, weighed and cleaned as specified in assembly procedures and assembled into the fuel pins.

Qualification of Subassemblies by Thermal Cycle Testing

A thermal cycle test was conducted with fuel pins and fuel pin parts to determine fuel pin integrity and component compatability at thermal conditions similar to those encountered in the reactor tests. Chronologically this testing was done after all mechanical assembly and process qualification had been completed. Hence, thermal cycling represented a final proof test for fuel pins, thermocouples and other critical components. Fuel pins and component parts were included in the test as follows:

1. Fuel Pin D-1 (D/2 Size)
2. Fuel Pin D-3 (D/2 Size)
3. Fuel Pin D-5 (D/2 Size)
4. "D" size thermocouple 16" (4.01×10^{-1} M) long with hot junction end in tantalum well.
5. (2) D/2 size thermocouples 16" (4.01×10^{-1} M) long one inserted in fuel pin D-1 thermowell and one inserted in fuel pin D-3 thermowell.
6. Samples Nos. 1 through 5, each made up of T-111 tube 1/2" (1.27×10^{-2}M) long, section of tungsten liner 1/2" (1.27×10^{-2}M) long and one depleted UN fuel pellet.
7. Sample No. 6 made up of W-Re-Mo liner without T-111 clad and with (2) depleted UN fuel pellets.
8. Sample No. 7 made up of tungsten liner without clad and (1) depleted UN fuel pellet.

All test items except UN fuel and thermocouples were acid cleaned and degassed before installation in the thermocycle furnace. Figure 20 is a photograph of the test specimens ready for installation into the thermocycle furnace.

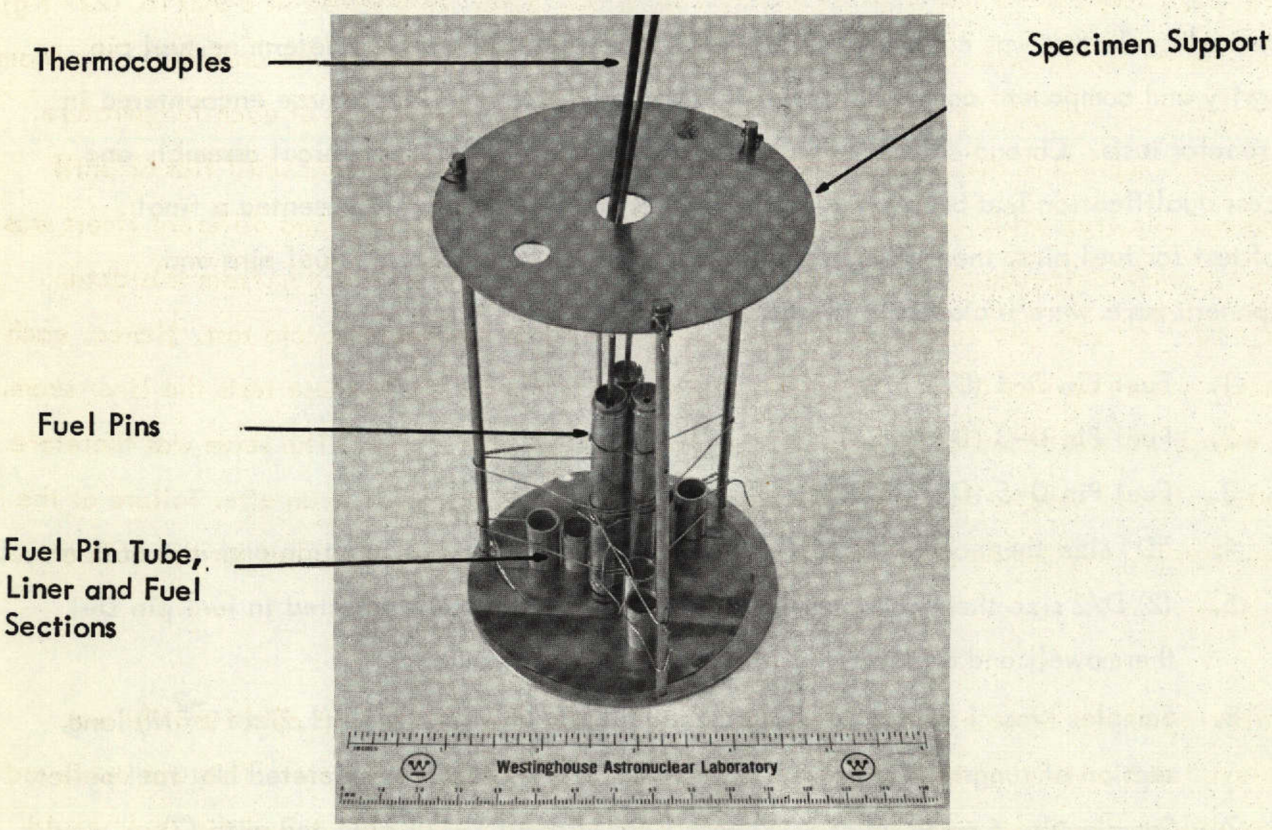


Figure 20. Specimens Ready for Installation in Thermocycle Furnace.

It was necessary to know the Ductile/Brittle transition temperatures of the tungsten liners in order to set the lower temperature requirement of the thermocycle test. It was desirable to cycle through this point since it was important to ascertain if brittle failure of the liners would occur from thermal cycling alone. A test was conducted as follows to determine the Ductile/Brittle transition temperature: End sections of liners Nos. 9, 10 and 21 were cut into 1/8" (3.18×10^{-3}M) wide discs and the molybdenum mandrel leached out leaving tungsten rings .318 (8.08×10^{-3}M) OD x .312 (7.90×10^{-3}) ID x 1/8" (3.18×10^{-3}M) wide. Rings were tested in a 500 lb. (227 Kg) Table Model Instron with a load readout range of 0-4 lbs. (0-1.81 kg). For uniformity the seam (ID protrusion) was always placed at the bottom during test. For testing at each temperature, rings were inserted in the Instron, stabilized at test temperature then bent until flat or until breakage occurred while recording displacement and load. A ring from two different liners was tested at each temperature level except 175°F (352°K) and 150°F (339°K). From this data, 100°F (311°K) was selected to be the lower temperature of the thermalcycle test. Hence, each thermal cycle required 6 hours to complete as shown in Figure 22. In these tests the liner seam, see Figure 19, was found to be weaker than the remainder of the liner. The seam was therefore always oriented tangent to the platten permitting the test to continue even after failure at the seam. Hence, two curves are shown in Figure 21, one for the seam, the other for the bulk of the liner.

Monitoring of the furnace pressure for deviation from the normal heat cycle profile was employed as a method of leak checking sealed fuel pins throughout the test. This was achieved by monitoring ion pump current which is indicative of system pressure. A fuel pin leak would result in release of helium accompanied by a considerable pressure rise since helium is not pumped efficiently by sputter ion pumps. Any abnormal pressure rise could be reason to suspect that fuel pins had started to leak. Figure 23 is a typical pressure profile for one cycle.

A pressure burst occurred near the end of the first cycle (temperature 110°F (316°K)) near the beginning of the eighteenth cycle (temperature 1940°F (1333°K)) and on cooldown of the 21st cycle (temperature 1830°F (1272°K)). The pressure deviation were believed to be gas

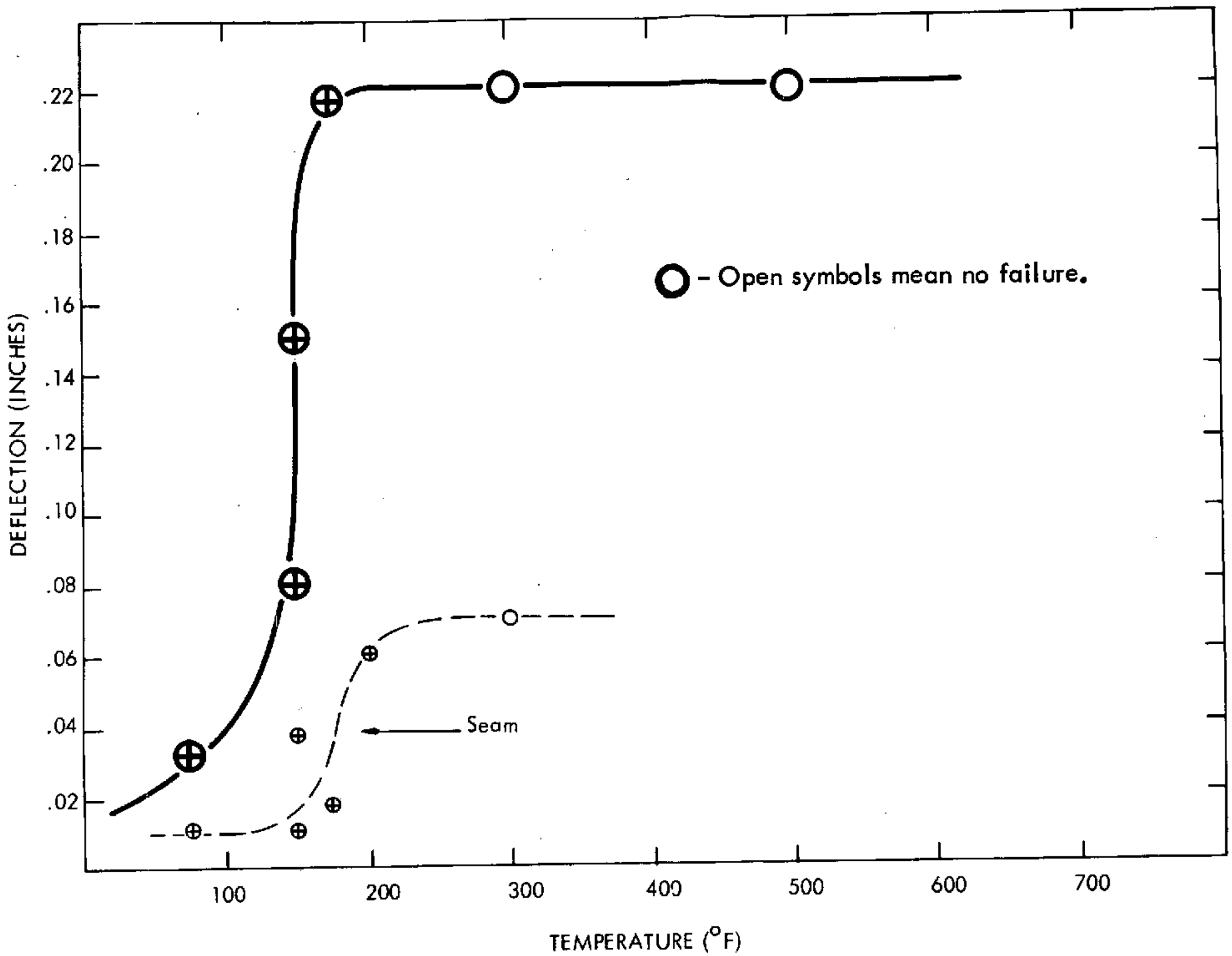


Figure 21. Ductile/Brittle Transition for Tungsten Rings
(.318 OD x .312 ID x .125) Cut from NASA Gas Pressure Bonded Foil Liners.

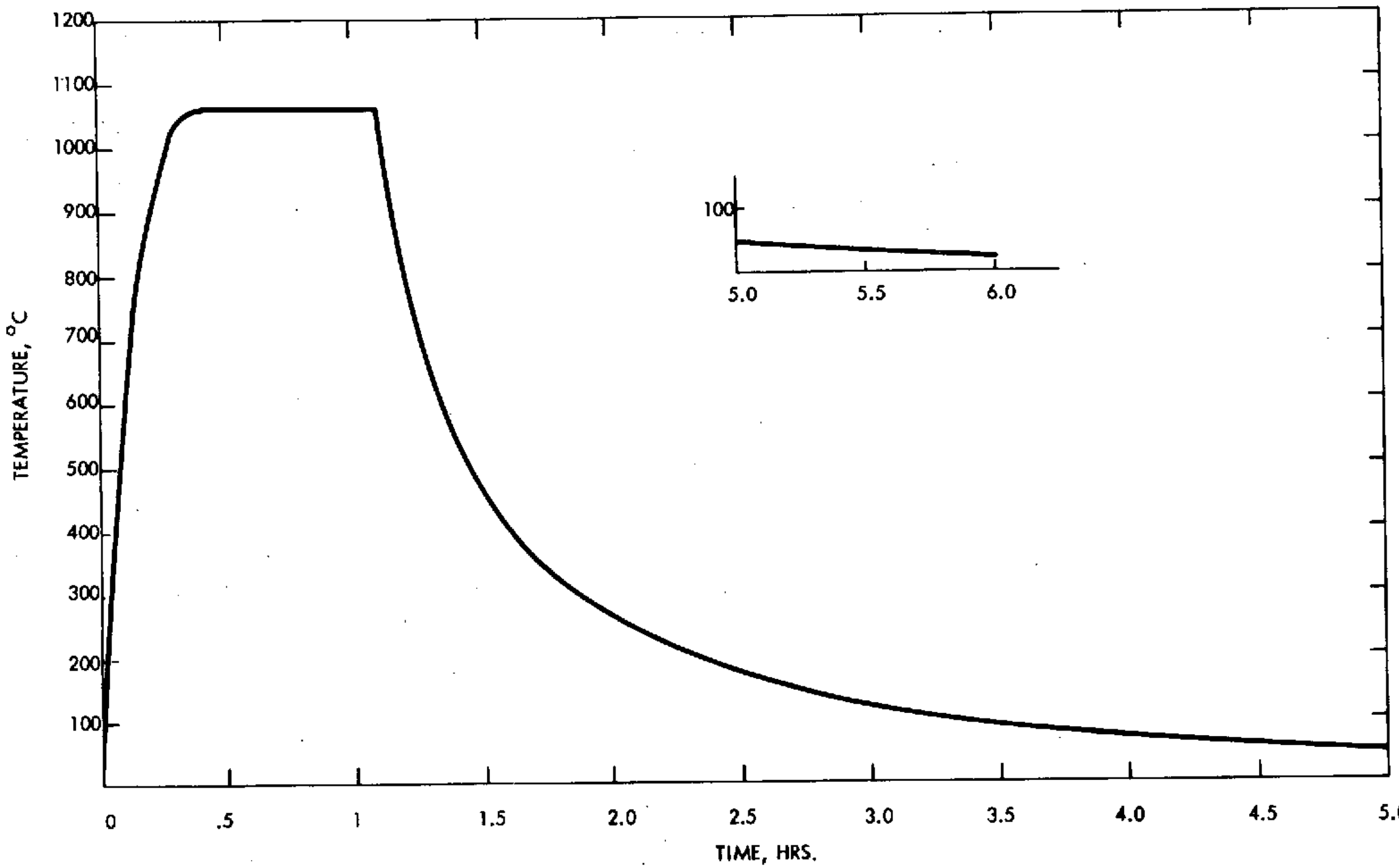


Figure 22. Typical Temperature Profile Thermocycle Test

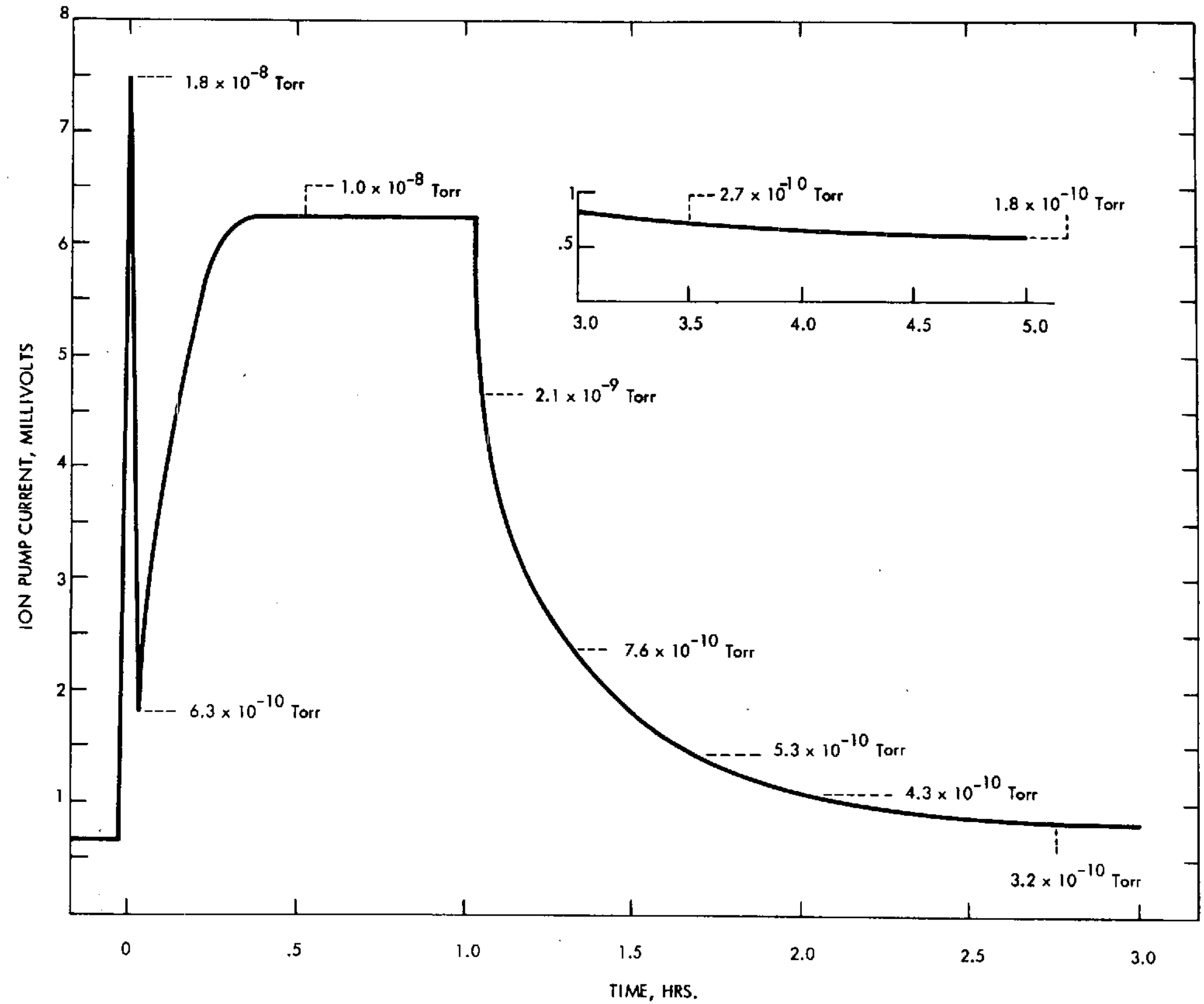


Figure 23. Typical Pressure Profile Thermocycle Test.

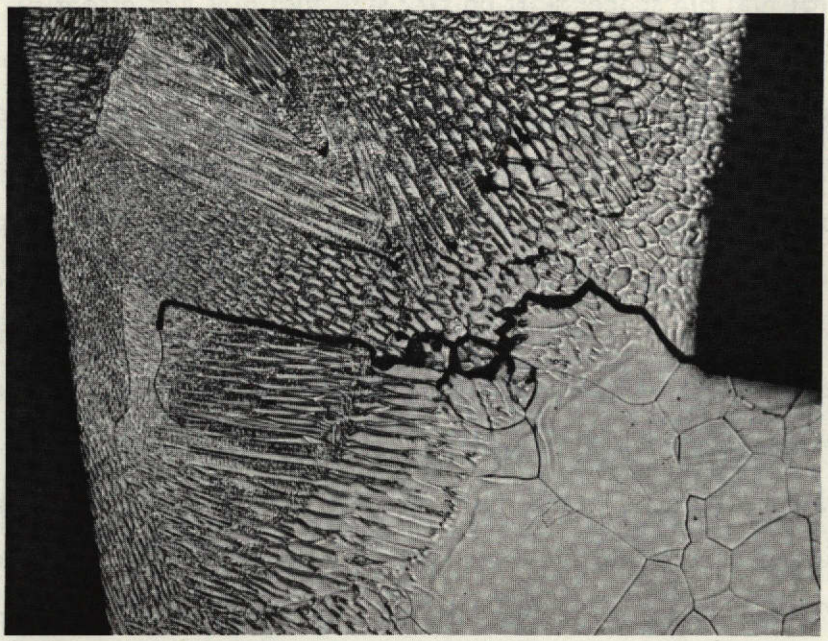
releases from the fuel pins and subsequent inspection when the furnace was opened after 25 cycles revealed that all three fuel pins were leaking at the final closure hole weld. Figure 24 is a microphotograph of the failed weld on fuel pin D-5.

A development program was conducted to determine the changes necessary in the final seal weld procedure to produce a leak tight weld. A change in the top end cap design which eliminated the integral fuel pin spacer skirt on D/2 size fuel pins was essential. This modification which is shown in Figure 25, improved access to the closure weld hole allowing greater flexibility in welding. While metallographic analysis had not pin-pointed the failure cause, it was apparent that a more controlled process was required. The fuel pin assembly chamber was modified by the addition of a fixed welding head with improved arc starting capability. A new process was developed which included a specified weld current and time cycle along with a controlled taper of current to eliminate possible crater defects in the small spot welds. A fixed gap established by "feeler" gage assured that contamination by the tungsten electrode would not occur. Test welding also demonstrated that the use of a small filler wire, preplaced in the seal hole resulted in more consistent sealing at lower power and provided a more positive arc strike. The details of the technique are given in procedure sheets 70336-13 and -14 in the Welding and Forging Section of Appendix I.

The use of a T-111 alloy electrode was also explored in the seal weld development effort. Results were not satisfactory due to melting of the electrode tip (regardless of configuration) before hole sealing. This caused increased arc length and spreading in an uncontrolled manner.

Two D/2 size test fuel pins (empty) Figure 25, were seal welded on each end for evaluation in thermal cycle testing using the new design end caps. Four welds were produced, two with filler wire and two without wire. On one of these welds, the weld time was extended slightly allowing more fusion to occur on the small end cap. This resulted in electrode contact and sticking to the weld.

Closure Weld



150X

Figure 24. Final Closure Weld Failure Fuel Pin D-5
After 25 Thermal Cycles

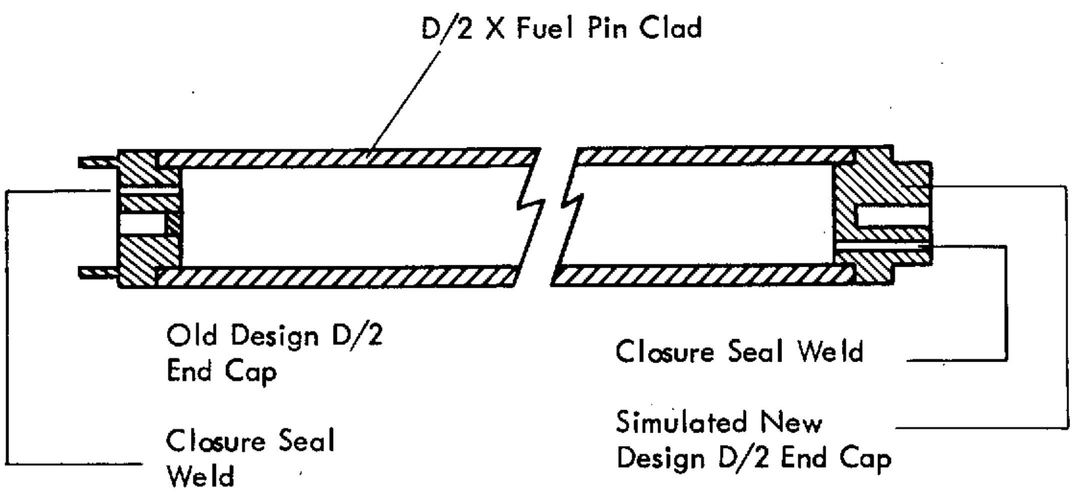


Figure 25. Simulated Fuel Pin for Seal Weld Test.

In addition, the fuel pins that had been thermal cycled were repaired prior to further thermal testing. The repair was performed by tungsten arc welding a small cap on the defective ends of these small D/2 size fuel pins.

All specimens as previously listed on page 40, were examined at the end of 25 thermal cycles, see Figure 26, and appear relatively unchanged except for the seal weld failure of the three fuel pins. Fuel pellets and liners were easily removed from the T-111 clad on five of the seven small specimens. Fuel pin D-5 and small sample No. 4 were removed from thermocycle test and examined as follows:

Fuel pin D-5 was mass spectrometer leak checked and found to be leaking at the small hole seal weld (as stated above). All welds passed dye penetrant inspection except for the final spot seal weld. The fuel pin was measured and x-rayed and these data were compared to pre-test data with no significant change. This fuel pin was disassembled by machining off the end cap to tube welds at each end and removing end caps, Figure 27. The tungsten washer part No. 11 (nearest end caps) were both broken. This was believed to be caused by the center hole in washer being too small to fit over the radius at the junction of the end cap and thermowell. This hole was enlarged for future assemblies. Another part 11 washer nearest the fuel at the bottom end was broken during disassembly. The thermocouple protective tube part No. 9 was broken 1/8" from the bottom of the thermocouple well of the top end cap and also in the area of the slot. There was a slightly discolored area on the thermocouple protective tube in the vicinity of the first fuel pellet from each end. Fuel and tungsten liners were removed intact from T-111 clad. Fuel liner and clad appear unchanged from the time of installation. The spherical spacers at the bottom end were distorted at the center hole reducing their height. This was noted in the x-ray before test and was probably caused at assembly. The fuel pin clad was metallographically examined at center and near each end for evidence of change from pre-test condition. Figures 28, 29, 30, 31 and 32 are photomicrographs of typical areas. A precipitate, probably a carbide, is evident in many areas

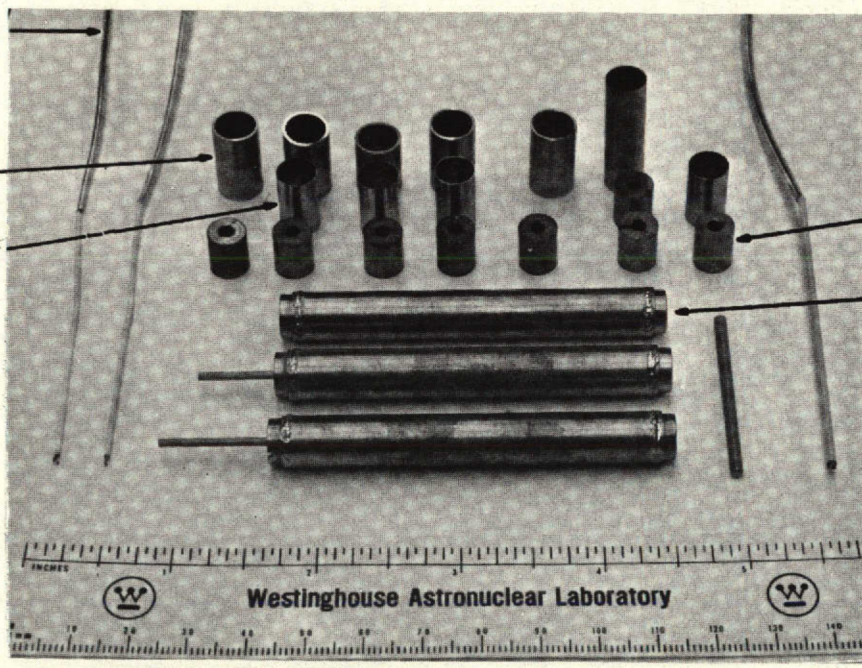


Figure 26. Thermocycle Test Specimen After 25 Cycles.

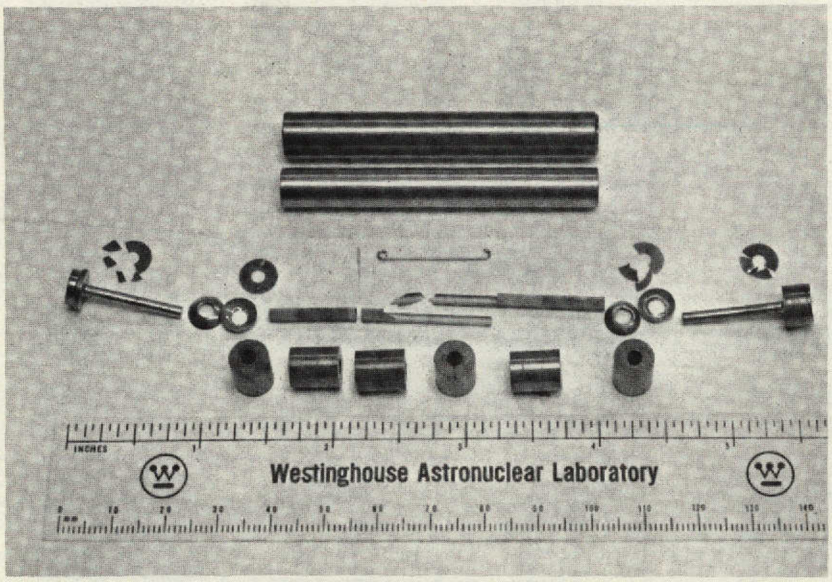
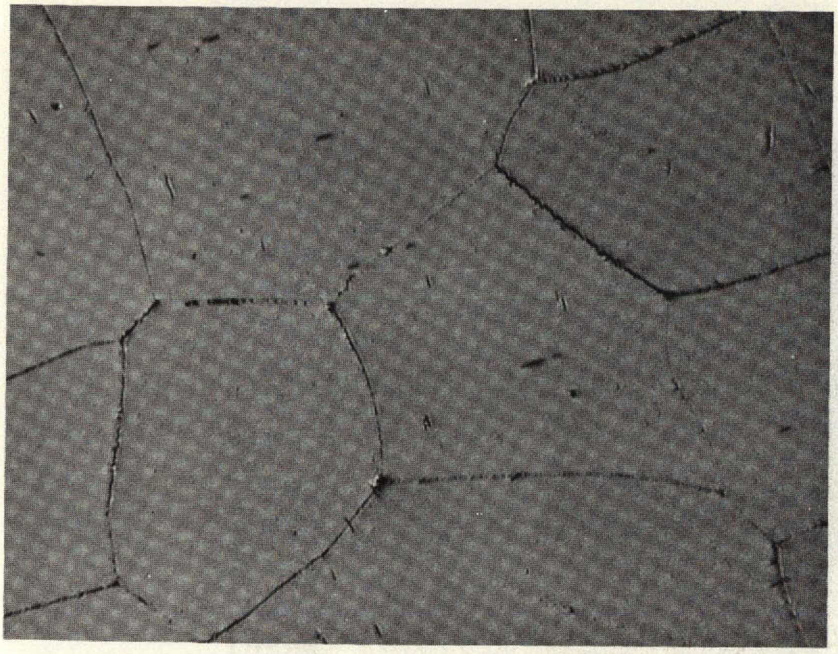
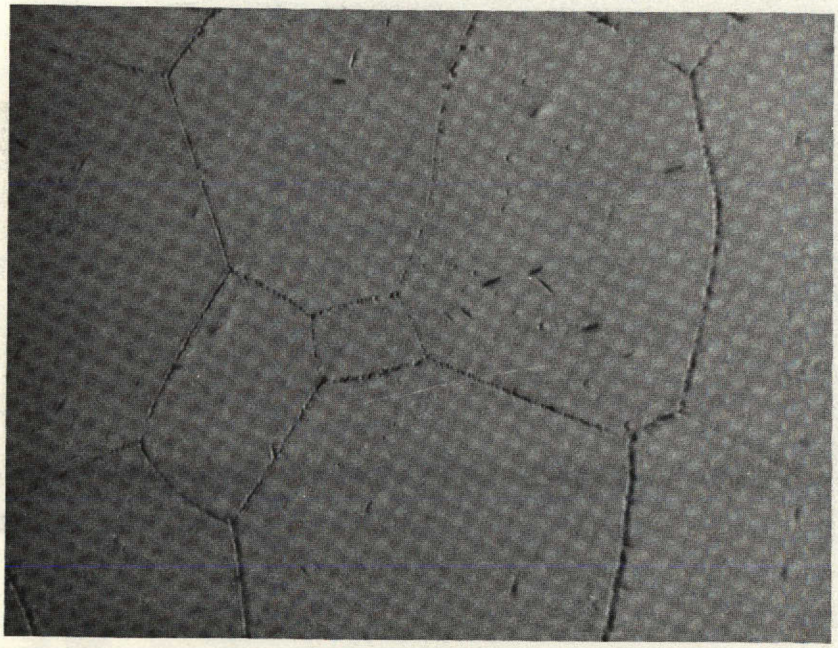


Figure 27. Fuel Pin D-5 Disassembled After 25 Thermal Cycles.



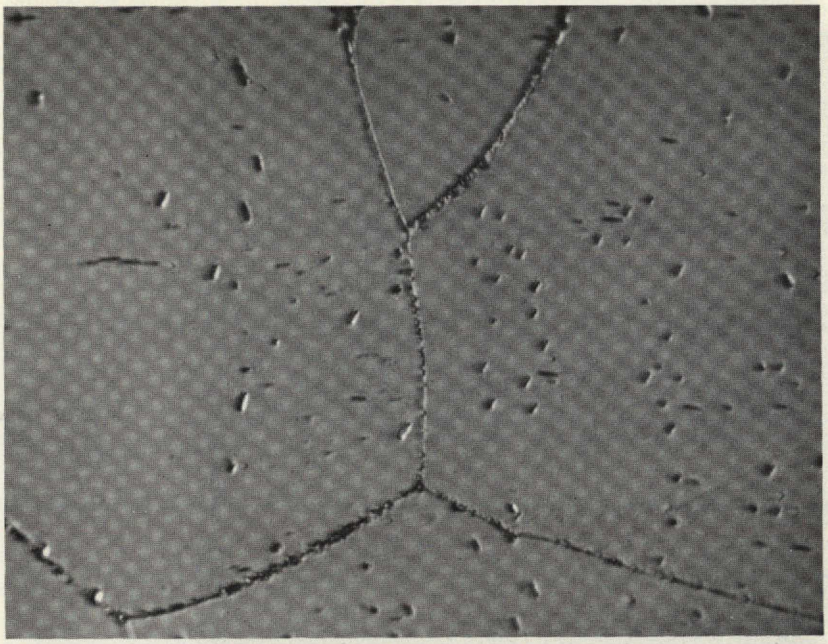
Transverse

Figure 28. Fuel Pin D-5 After 25 Thermal Cycles, Near ID of Clad at Top End Mag. 1500X



Transverse

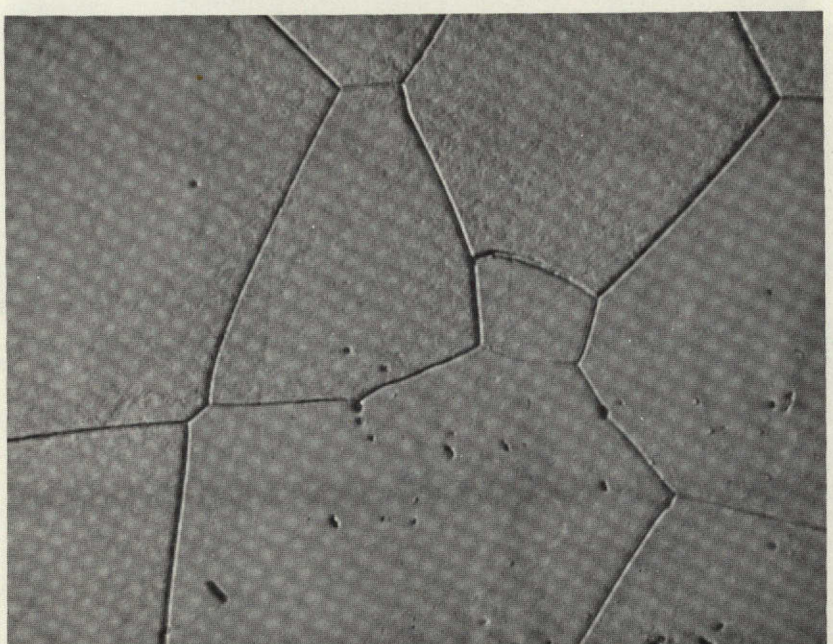
Figure 29. Fuel Pin D-5 After 25 Thermal Cycles, Near OD of Clad at Top End Mag. 1500X



Longitudinal

20,678

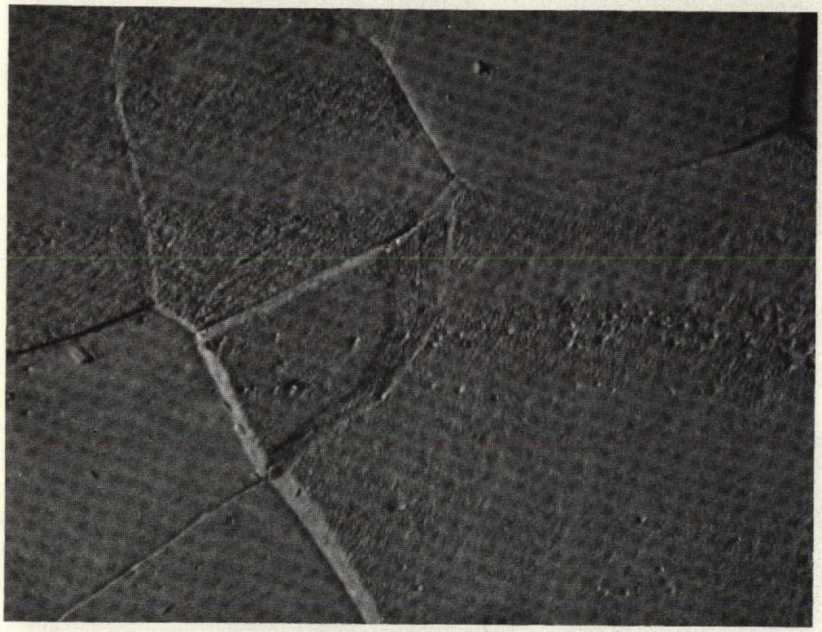
Figure 30. Fuel Pin D-5 After 25 Thermal Cycles, Near ID of Clad at Center Mag. 1500X



Transverse

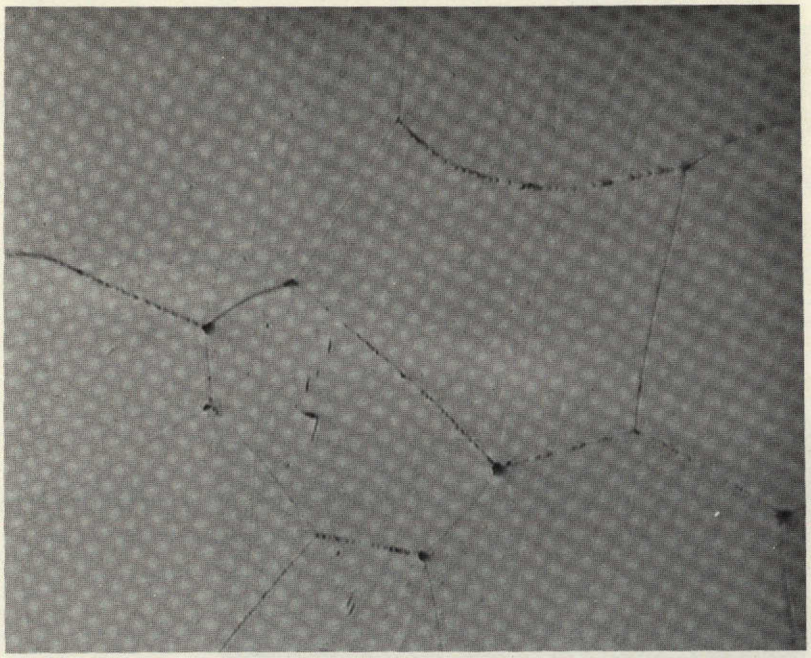
20,677

Figure 31. Fuel Pin D-5 After 25 Thermal Cycles, Near ID of Clad at Bottom End Mag. 1500X



Longitudinal

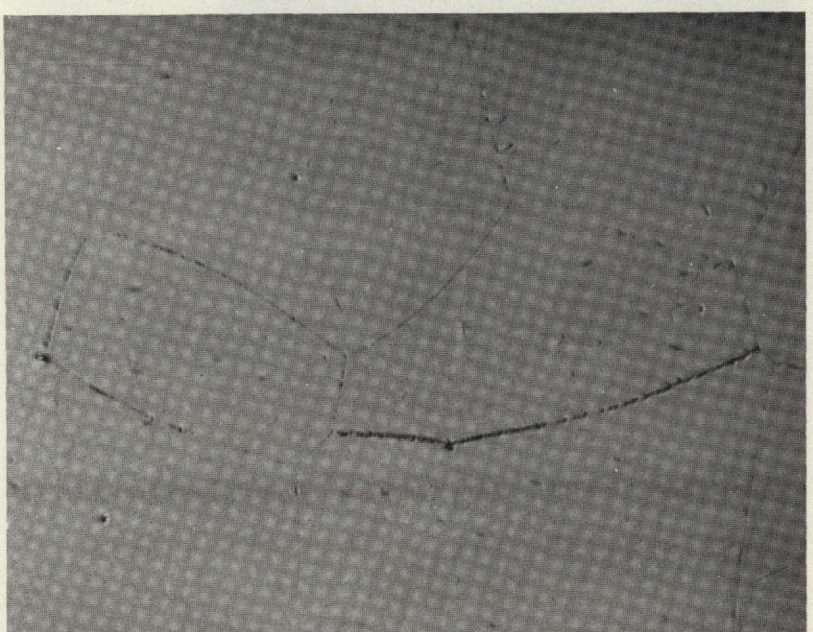
Figure 32. Fuel Pin D-5 After 25 Thermal Cycles, Top Thermocouple Well Near OD. Mag. 1500X



Transverse

20,671

Figure 33. Sample No. 4 After 25 Thermal Cycles
Clad Near ID Mag. 1500X



Transverse

20,671

Figure 34. Sample No. 4 After 25 Thermal Cycles
Clad Near OD Mag. 1500X

particularly in grain boundaries. A hardness profile across the wall showed nothing unusual. The small cladding sample No. 4 appeared unchanged from pretest condition.

Simulated fuel pins for seal weld test and fuel pins D-1 and D-3 were mass spectrometer leak checked, dye penetrant inspected, cleaned and reinstalled in the thermal cycle test furnace along with small test samples No. 1, 2, 3, 5, 6 and 7, two D/2 size thermocouples and one D size thermocouple. The thermal cycle test was restarted and operated for 25 additional (50 total) cycles between room temperature and 1940°F (1333°K). No unexpected pressure bursts were noted. Cycling was interrupted at the end of 50 cycles and fuel pins D-1 and D-3 and the simulated fuel pins for the seal weld tests were mass spectrometer leak checked. No leaks were detected. Fuel pin D-1, small sample No. 5 and the D size thermocouple were removed from the test, a section of .755 (1.92×10^{-2}M) OD T-111 tubing was installed and the test was restarted.

Fuel pin D-1 was disassembled and visually examined. Figure 35 is a photograph of the disassembled pin. The tungsten liner could not be removed from this fuel pin tube and examination of the liner with a boroscope revealed a circumferential crack approximately in the axial center of the liner tube. At the end of 75 cycles the test was again interrupted due to the furnace heating element shorting together electrically. Test specimens were visually examined with nothing unusual noted and the test was restarted after repairing the furnace heater.

Pressure bursts were recorded during cooldown near the end of cycles No. 75, 77 and 78 raising the possibility that the fuel pin and/or simulated fuel pins were leaking. The thermo-cycle test was terminated at the end of 91 cycles and the two simulated fuel pins for seal weld testing as well as fuel pin D-3 were mass spectrometer leak checked, alcohol bubble tested and visually inspected for signs of leaks. All tests indicated that there were no leaks and all welds were sound. The recorded pressure bursts during the test were probably caused by ion-pump instability resulting in the release of buried inert gas in the pump plates.

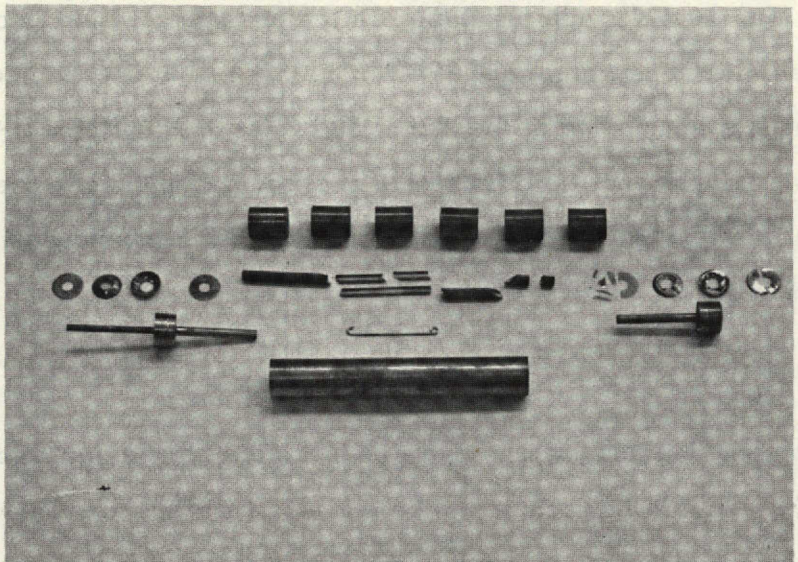


Figure 35. Fuel Pin D-1 Disassembled After 50 Thermal Cycles.

A macroscopic examination was made of all specimens after 91 cycles. Figure 36 is a photograph of these specimens. There was no reaction or change noted on any of the T-111 or tungsten parts at this level of examination. Figure 37 is a photograph of a green deposit found on the "D" size thermocouple which was tested the last 41 cycles. This deposit, which coated the last inch of the "D" sized thermocouple sheath on the hot end was not noted on either of the D/2 size thermocouples or the "D" size thermocouple that was tested in the previous 50 cycles. There also appeared to be a coating covering much of the chromel alumel wire in the hot zone of the "D" size thermocouples, and a lighter coating on the D/2 size. Figures 38 and 39 show photographs of the D and D/2 sized thermocouple hot junctions.

Evaluation

In general, the fuel pin system appeared to have no uncompatibilities. No detectable undesirable interaction between components was observed. Figure 40 is a photograph of fuel pin D-3 disassembled after 91 cycles. The tungsten liner could not be removed from the fuel pin tube but it appeared unbroken and uncracked.

Metallographic examination was performed on all test specimens. Figures 41 through 61 are photomicrographs of representative areas of each of these specimens. There appears to be a precipitate, probably a carbide, throughout most of the fuel pin cladding and small sample tubes which were thermocycled. Figure 42 is a transverse view of D-1 fuel pin tube near one end and indicates a greater concentration at the ID than the OD. However, investigation at high magnification after repolishing and etching to retain the precipitate (Figures 44 and 45) revealed very little if any difference in this specimen or in any of the specimens investigated. Furthermore, Figure 43 is the same tube near the opposite end of the fuel pin D-1 and does not appear to have the precipitate gradient. Figures 46 and 47 are transverse views of D-3 fuel pin tube after 91 cycles near one end and appear to have very little of the precipitate. The fact that this precipitate does not increase with time in the thermocycle test and is not present in the end caps indicates that it is not a function of

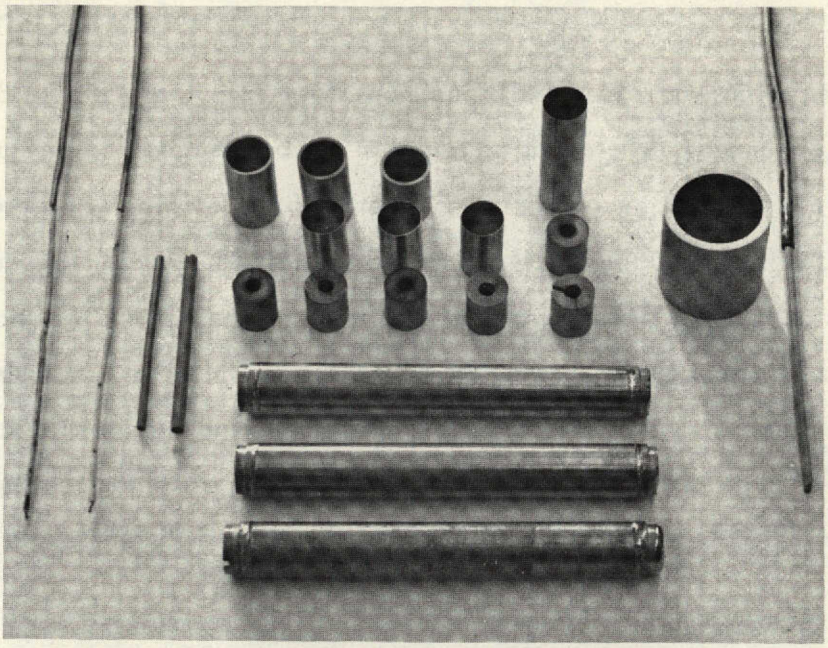


Figure 36. Thermal Cycle Test Specimen After 91 Cycles

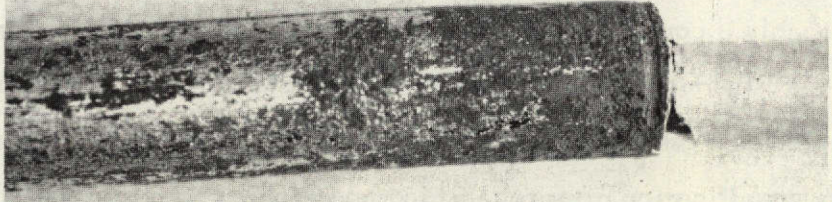


Figure 37. Deposit on Stainless Steel Sheath of "D" Size Thermocouple at Hot End After 41 Thermal Cycles Mag. 9X

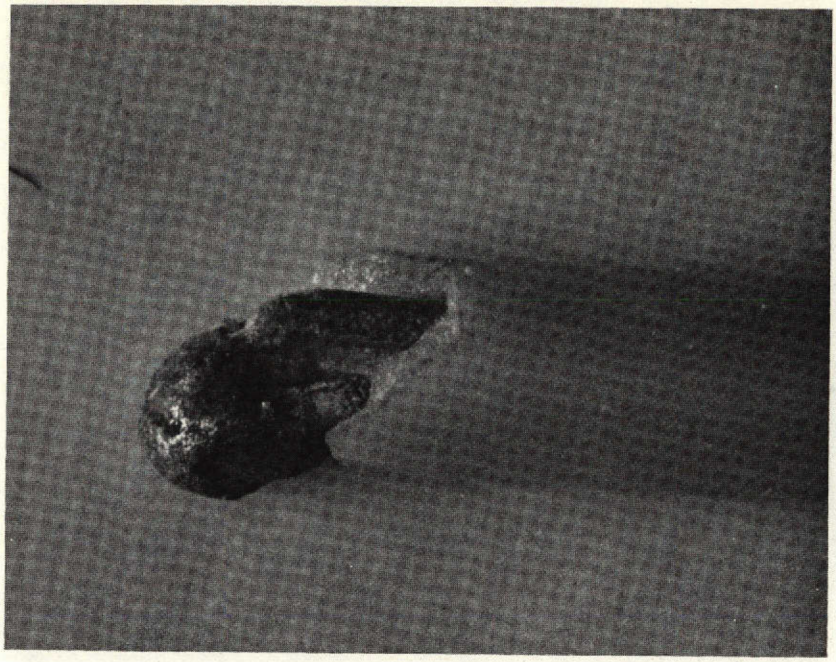


Figure 38. Hot Junction of "D" Sized Thermocouple After 41 Thermal Cycles
Mag. 19X

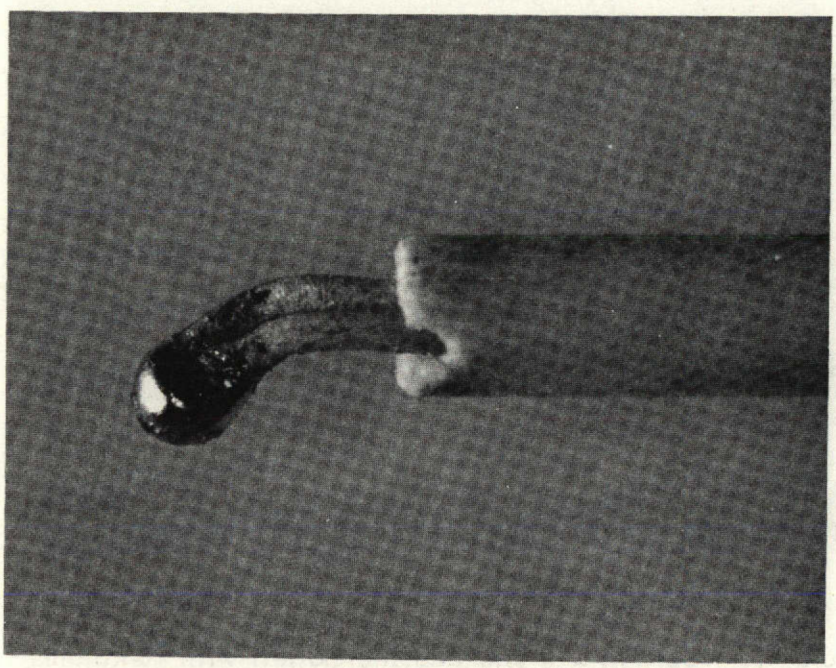


Figure 39. Hot Junction of D/2 Size Thermocouple After 91 Thermal Cycles

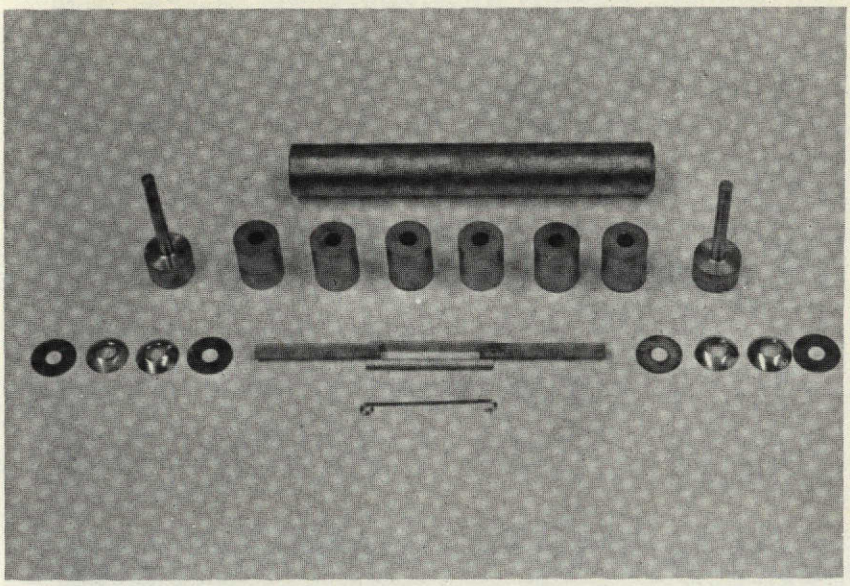
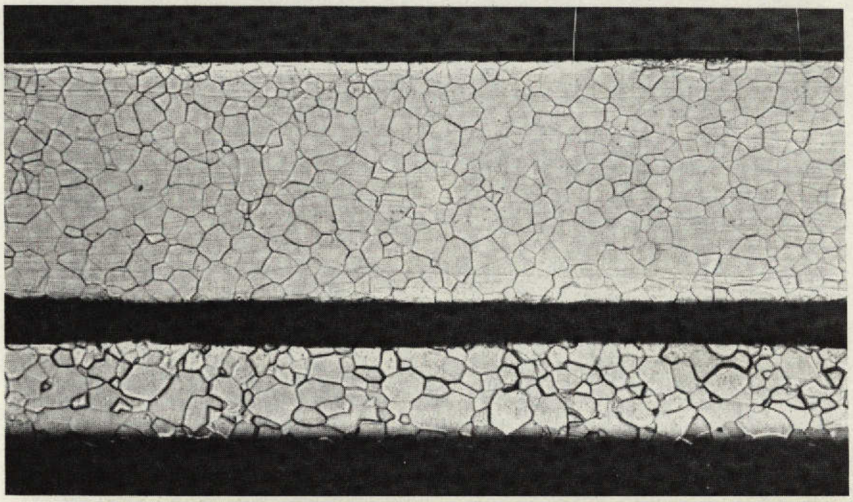


Figure 40. Fuel Pin D-3 Disassembled After 91 Thermal Cycles

T-111
Thermowell



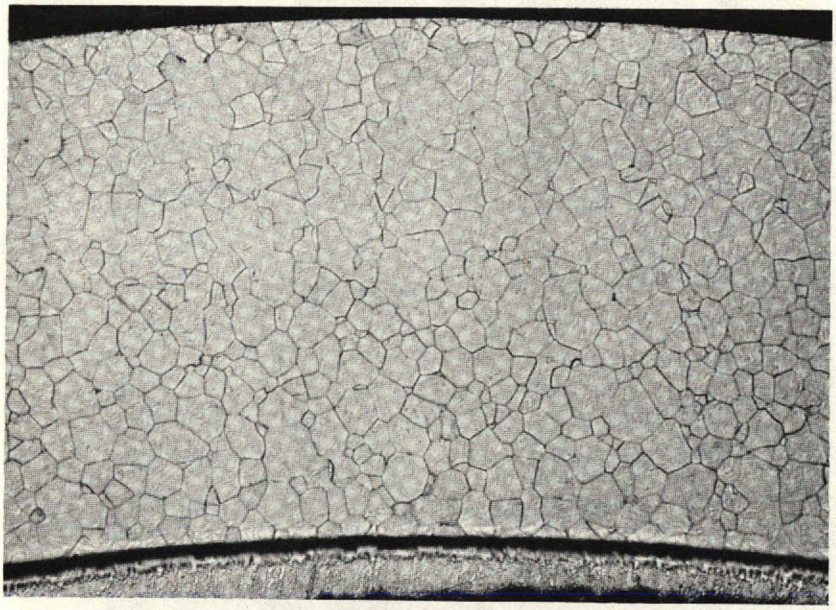
Longitudinal

Ta Thermo-
couple well

Figure 41. Fuel Pin D-1 End Cap Thermowell with Tantalum Thermocouple Well Inserted. 50 Cycles 100X

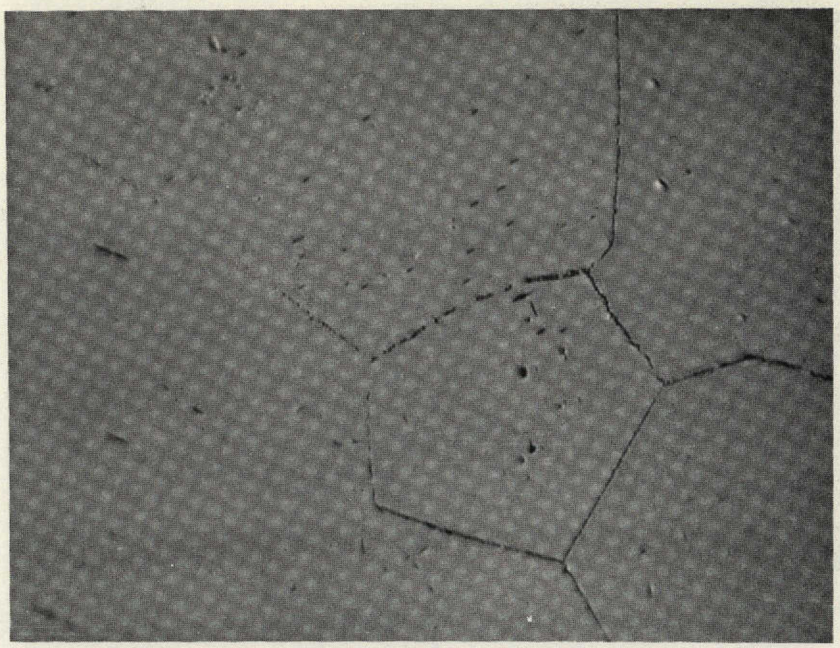
Transverse

Figure 42. D-1 Fuel Pin Tube & Tungsten Liner Near End Cap. 50 Cycles 100X



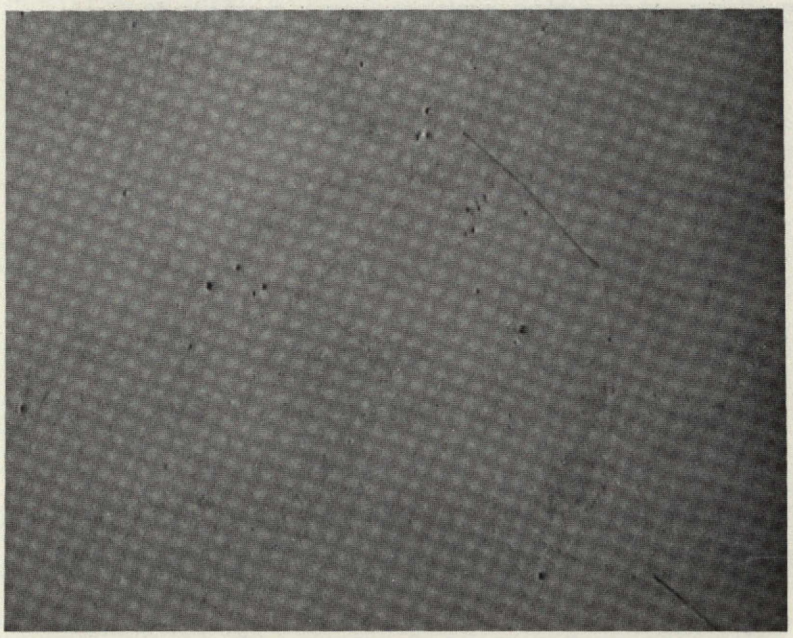
Transverse

Figure 43. D-1 Fuel Pin Tube & Tungsten Liner Near End Cap. 50 Cycles 100X



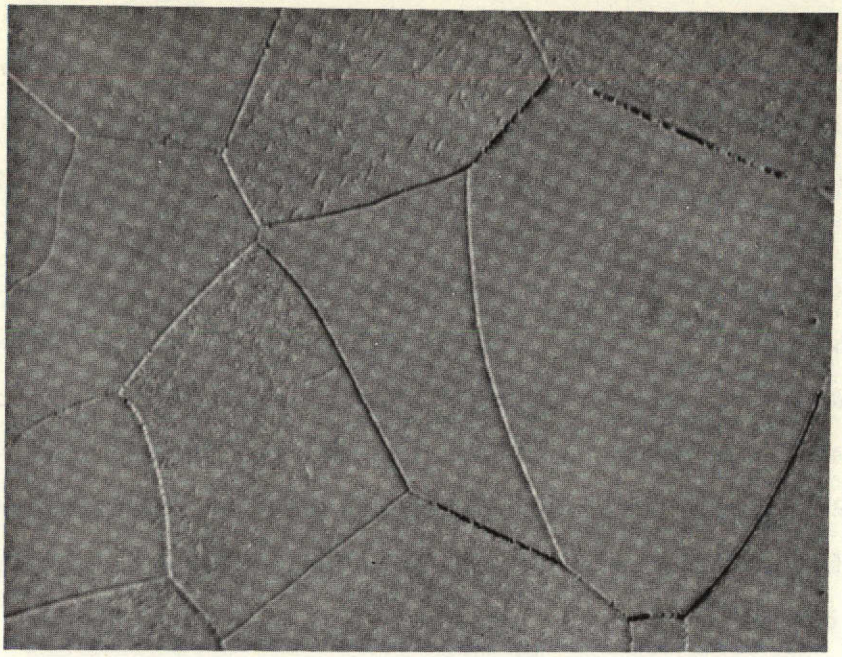
Transverse

Figure 44. D-1 Fuel Pin Tube Near ID. 50 Cycles 1500X



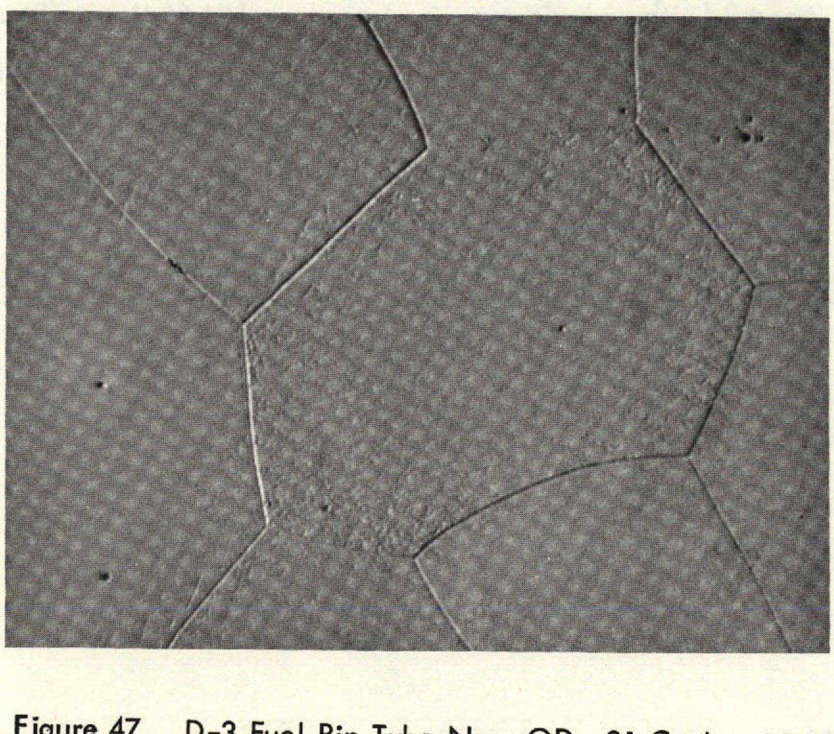
Transverse

Figure 45. D-1 Fuel Pin Tube Near OD. 50 Cycles 1500X



Transverse

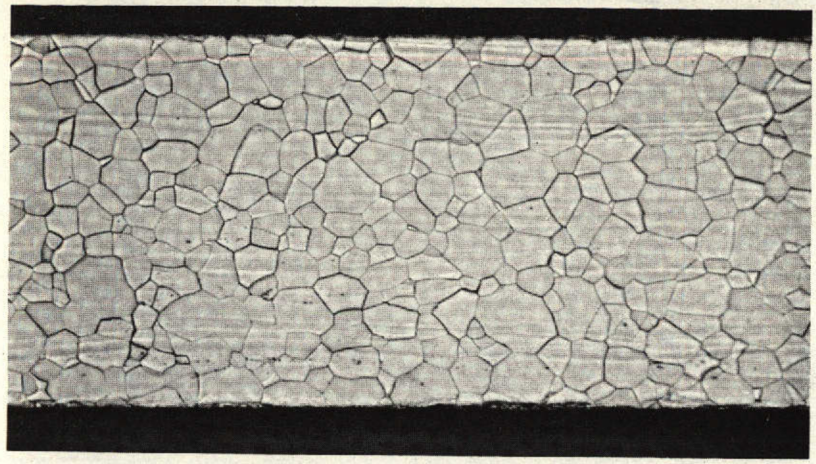
Figure 46. D-3 Fuel Pin Tube Near ID. 91 Cycles 1500X



Transverse

Figure 47. D-3 Fuel Pin Tube Near OD. 91 Cycles 1500X

the fuel pin system but probably inherent in the raw material. Figure 48 is a longitudinal view across the bottom end cap thermowell wall of fuel pin D-3 after 91 cycles. Here the absence of any precipitate is obvious. Possibly the precipitates observed in this study are artifacts produced in metallography because the quantity of precipitates reduced drastically with the lighter etch. Metallographic preparation of T-111 requires great care in this regard since the etching has proven to be very sensitive to prior thermal-mechanical processing history. Hence, the higher magnification metallography mentioned above, which was done very carefully to retain precipitates, is probably conclusive in showing this material to be normal. Figures 49 through 55 are photomicrographs of the open samples included in the test. There was no significant difference between the appearance of these samples and the fuel pins. Figure 56 is a transverse view of a piece of 0.755 OD T-111 tubing after 41 thermo-cycles. No change was observed in this specimen due to test. Figures 57 and 58 are tantalum thermocouple wells tested 91 cycles with chromel/alumel thermocouples inserted. No contamination or reaction was observed. Figures 59 and 60 are cross sections of the closure hole seal test welds No. 2 and 3 (with and without wire insert) cycled 66 times. Figure 61 is a transverse view of the T-111 tube used for the seal weld tests. No cracking, pitting, grain separation, precipitates or attack was noted on the welds, base metal around welds or the T-111 tube. Figure 62 is a microphotograph of typical "as received" material.



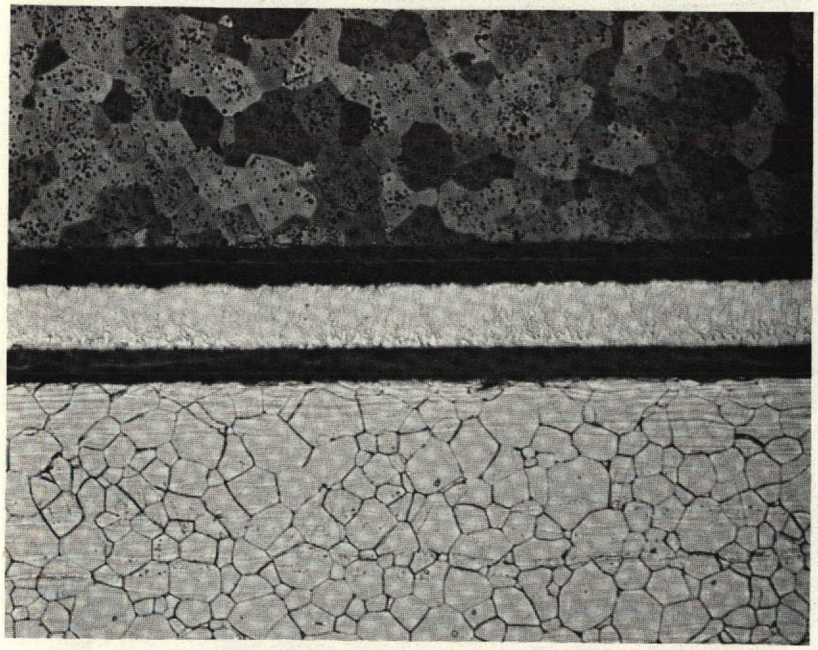
Longitudinal

Figure 48. D-3 Fuel Pin Bottom End Cap Thermowell After 91 Cycles. 150X

Un Fuel

Tungsten Liner

T-111 Tube



Longitudinal

Figure 49. Sample No. 1 After 91 Cycles, T-111 Tube - Tungsten Liner - UN Fuel. 100X

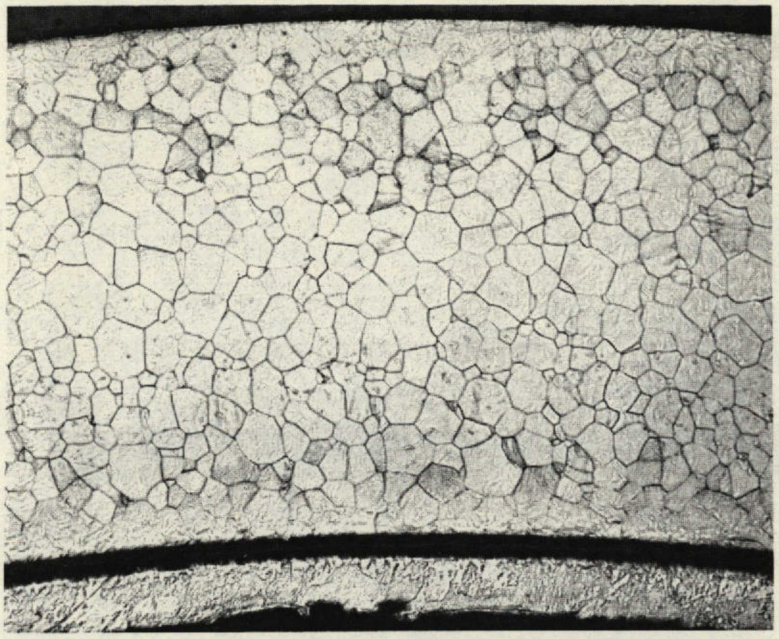


Figure 50. Sample No. 2 After 91 Cycles, T-111 Tube - Tungsten Liner. 100X

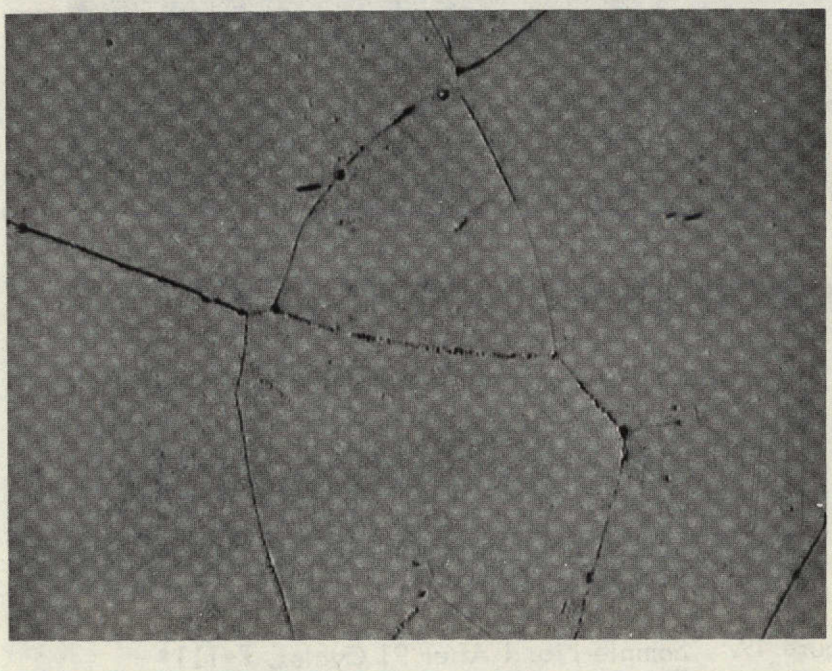
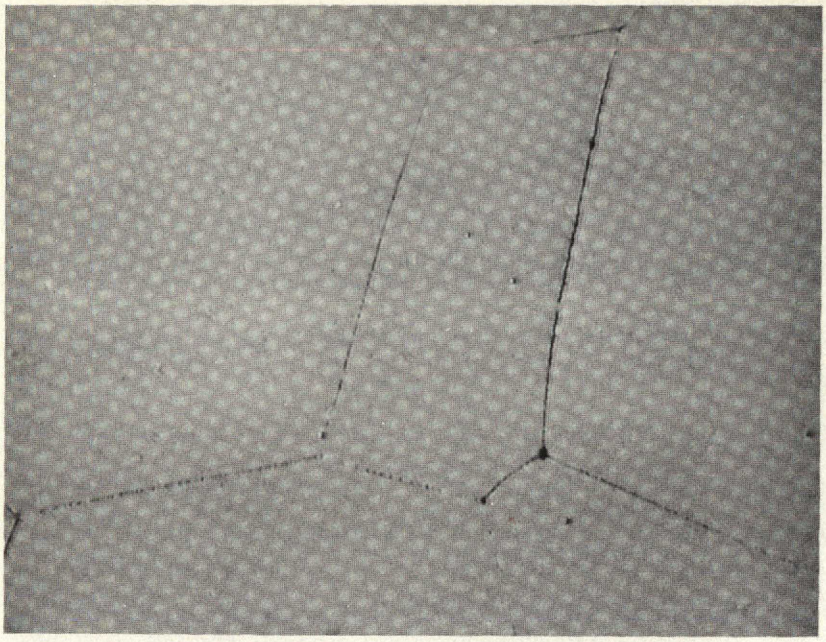
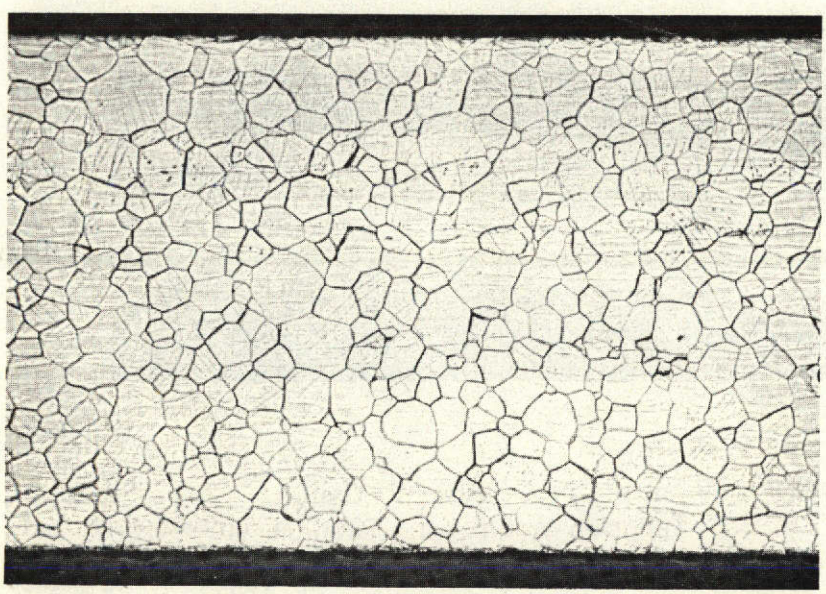


Figure 51. Sample No. 2 After 91 Cycles, T-111 Tube Near ID. 1500X



Transverse

Figure 52. Sample No. 2 After 91 Cycles, T-111 Tube Near OD. 1500X



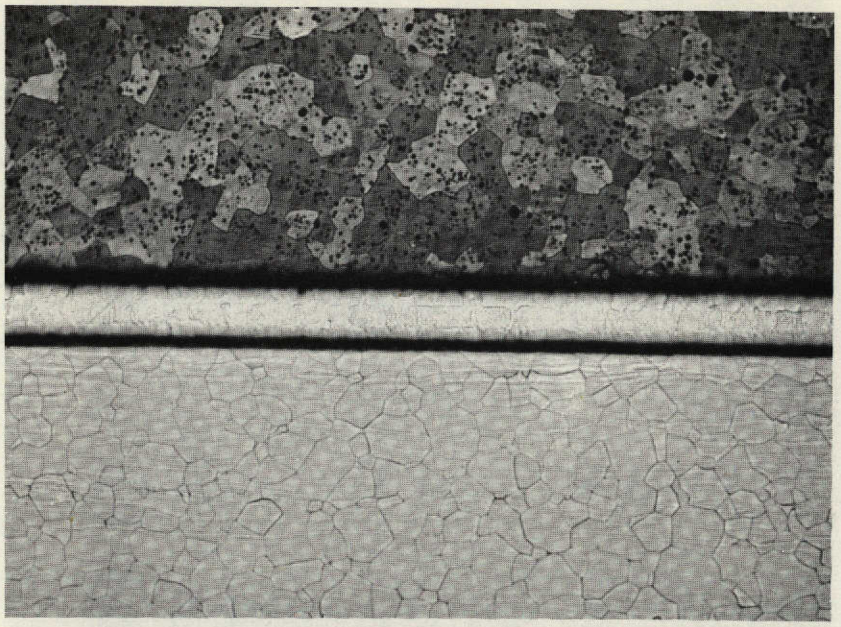
Longitudinal

Figure 53. Sample No. 3 After 91 Cycles, T-111 Tube 100X

Un Fuel

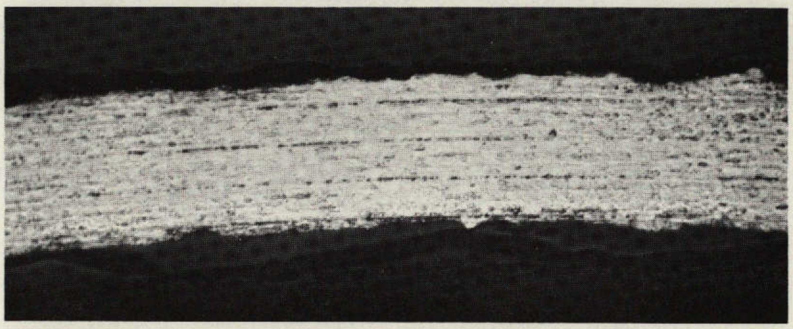
Tungsten
Liner

T-111 Tube



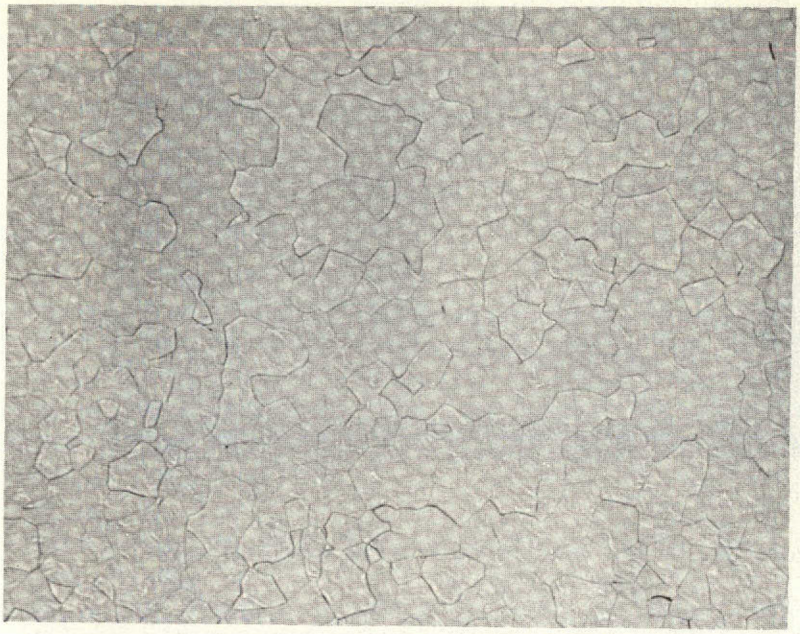
Longitudinal

F igure 54. Sample No. 5 After 50 Cycles, T-111 Tube - Tungsten Liner - UN Fuel 100X



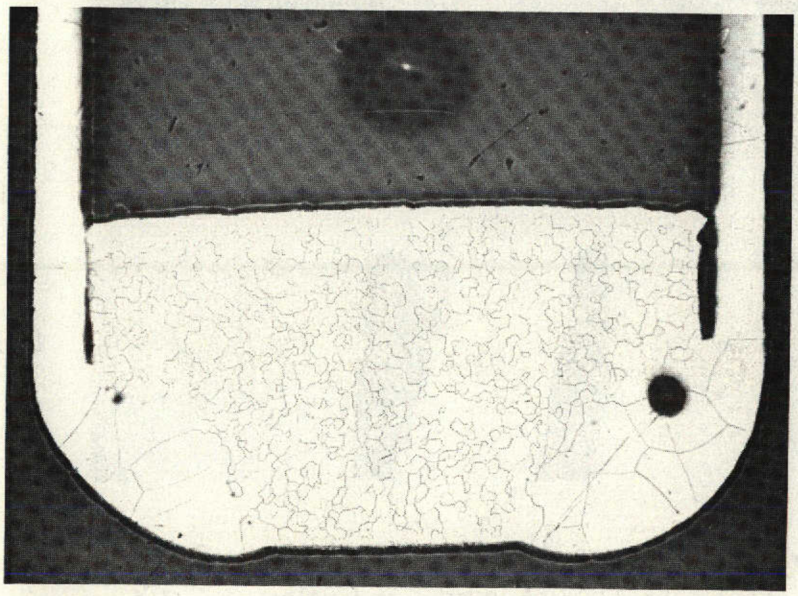
Transverse

Figure 55. Sample No. 6 After 91 Cycles, Tungsten Molybdenum Rhenium Liner 200X



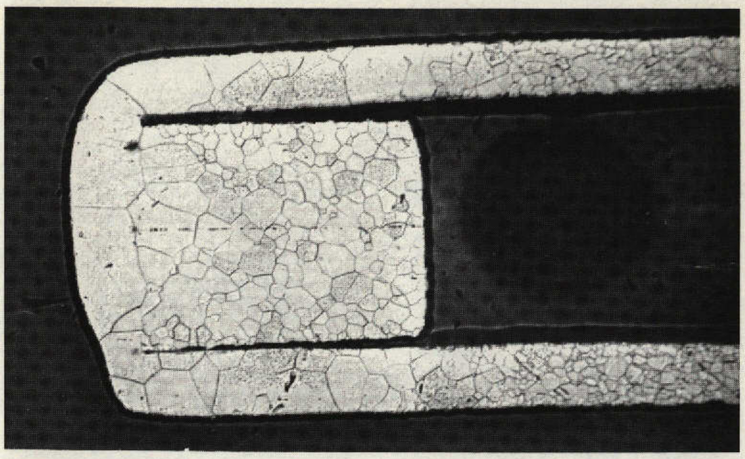
Transverse

Figure 56. 0.755 OD T-111 Tube After 41 Cycles
100X



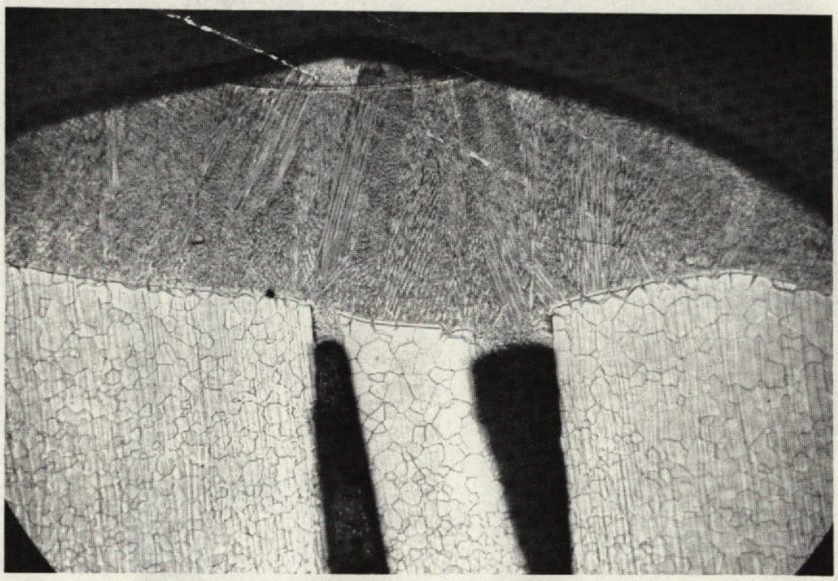
Longitudinal

Figure 57. "D" Size Tantalum Thermocouple Well After
91 Cycles. 40X



Longitudinal

Figure 58. D/2 Size Tantalum Thermocouple Well After 91 Cycles. 90X



Weld

Filler Wire

End Cap

Figure 59. Closure Hole Seal Test Weld No. 2 with T-111 Wire Insert. 66 Cycles 40X

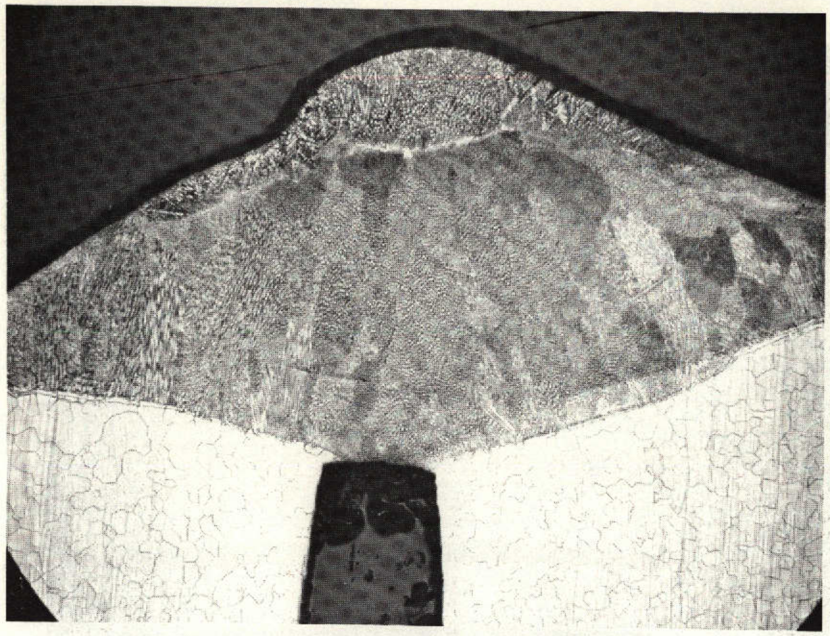
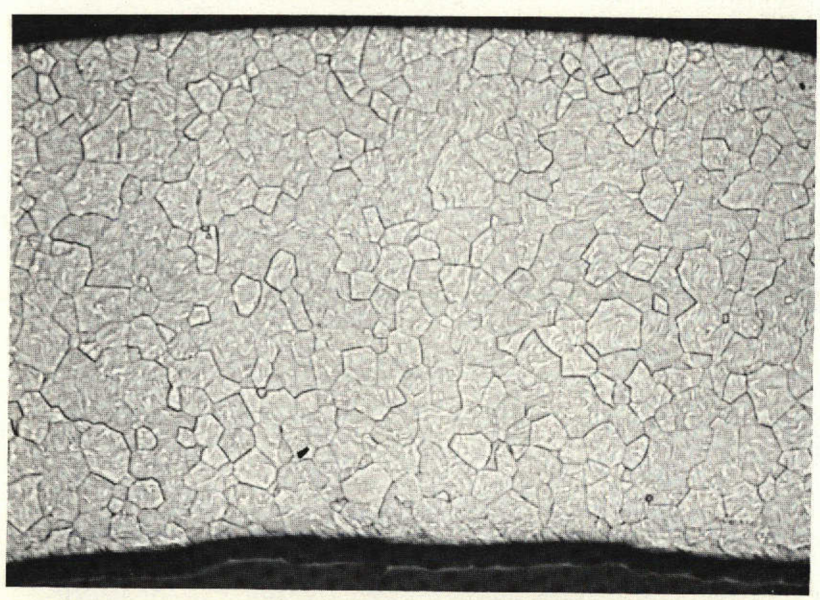
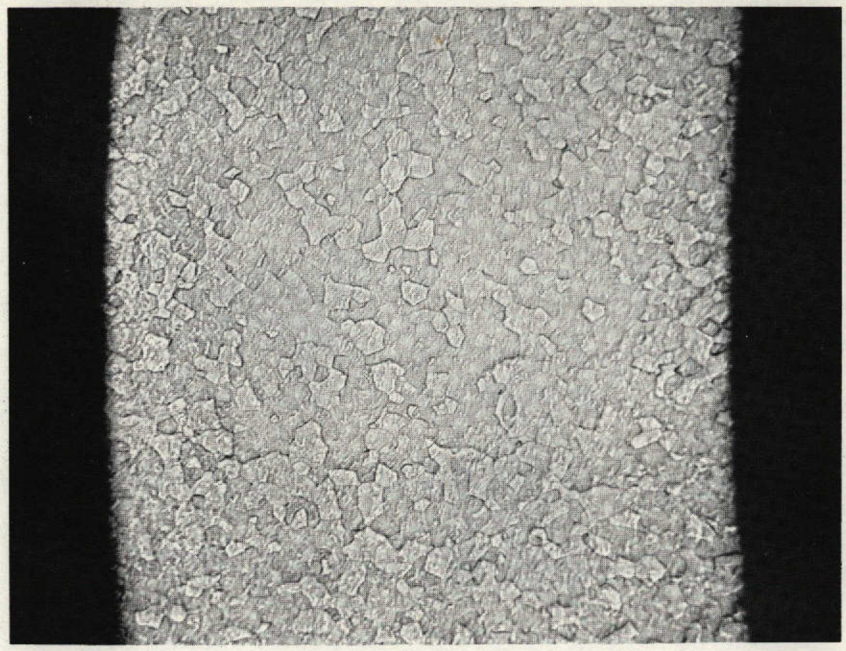


Figure 60. Closure Hole Seal Test Weld No. 3 Without Wire Insert. 66 Cycles 40X

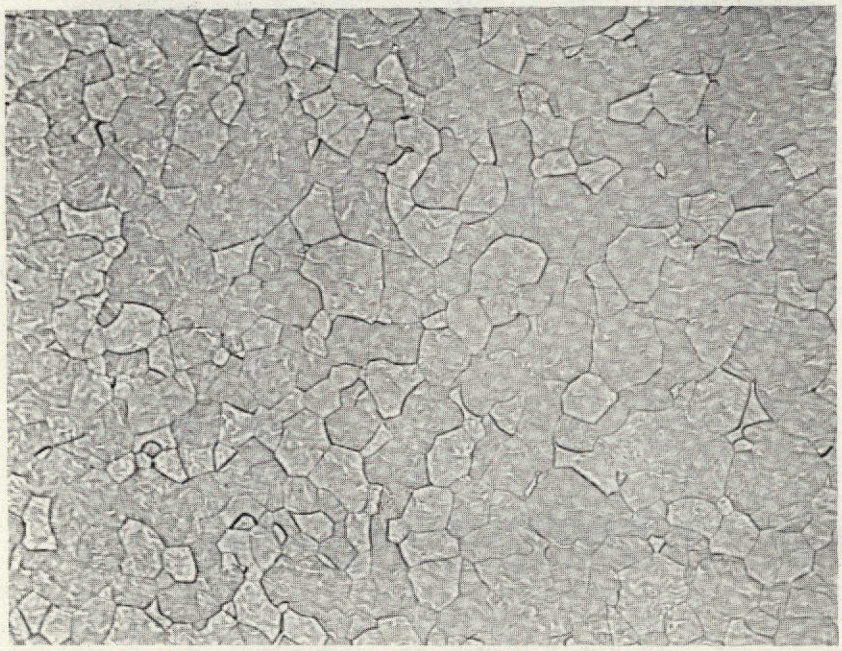


Transverse

Figure 61. T-111 Tube From Seal Weld Test No. 2 & 3. 66 Cycles 100X



50X



100X

Figure 62. 3/8 OD x .031 Wall T-111 Tubing
Raw Material as Received

IV. CONCLUSIONS AND SUMMARY OF RESULTS

The capsule assembly techniques developed and utilized in this program and described in this report were used to successfully fabricate forty one fuel pins and thirty capsule assemblies. Excellent results were achieved using these procedures. Electron beam welding was used as the major fabrication technique in this program. Capsule assemblies required as many as nineteen separate welds. Hence, very low weld reject rates were achieved to permit timely and economic completion of this program. In addition, the thermocouple design and construction using EB welding has proven to be exceptionally reliable during manufacture and provided a rugged product which could be easily handled.

The thermal cycle test proved to be of considerable value. Cycling results showed that an alternate procedure was required for final seal hole welding of fuel pins. This test also demonstrated that the fuel pin design was entirely acceptable short of achieving actual reactor test results.

The text and Appendices of this report present in detail and step by step all procedures and approaches utilized and required for producing irradiation test capsules of the highest quality.

APPENDIX A

PRÉ-IRRADIATION FUEL PIN DATA

PRE-IRRADIATION FUEL PIN DATA

A. Fuel Pin Data   Date Completed ________

1. Fuel Pin Ident. No. ________
2. Size Designation ________
3. Assembly Desgination ________
4. Length "L" ________
5. Weight ________

B. Fuel Pellet Data (Part No. 14)

ORNL Supplied Data

	Pellet No.	ORNL I.D. No.	Fuel Type	U^{235} Enrichment	U^{236} Content	Density	Max. O.D.	O.D.	I.D.	Length
Bot.	1									
	2									
	3									
	4									
	5									
Top	6									
		TOTAL								
	2	WESTINGHOUSE SPOT CHECK								
	4									

C. Fuel Pin Clad (Part No. 4)

1. Material ________
2. Ⓦ I.D. No. ________
3. Heat No. ________
4. Length ________
5. Weight ________
6. Dimensions before assembly

	Position	In Line with Notch		Line 90° From Notch	
		O.D.	I.D.	O.D.	I.D.
Bot.	1				
	2				
	3				
	CTR				
	4				
	5				
Top	6				

D. Tungsten Liner (Between Fuel & Clad) Part No. 10

1. Material________
2. Ⓦ Ident. No.________
3. I.D. (Mandrel O.D.)________, Plug Gage________
4. O.D.________
5. Bonded or loose________
6. Length________
7. Weight________

E. End Caps (Part No. 3)

1. Material________
2. Bottom end cap Ⓦ I.D. No.________ Weight________
3. Top end cap Ⓦ I.D. No.________ Weight________

F. Spacers (Part No. 12)

Location	No. Spacers	Thickness	Height	Weight
Top				
Bottom				
		Total		

G. Washers (Part No. 11

Location	No. Washers	Thickness	Weight
Top next to fuel			
Top next to end cap			
Bottom next to fuel			
Bottom next to end cap			
	Total		

Total Fuel Stack Length ________
Total Spacer Height ________
Total Washer Height ________
Weld Shrinkage Allowance ________

Total Stack Length________
Internal Length Between End Caps________

H. Thermocouple Protective Tube

1. Material_________
2. I.D._________
3. O.D._________
4. Slot size (where applicable)_________
5. Weight_________
6. Length_________

I. Fuel Pin Closure

1. Helium Pressure (psia)_________ Temperature (°F)_____________
2. Helium Purity (ppm) (From supplier certification)
   a. H_____
   b. Ne_____
   c. N_____
   d. O_2_____
   e. A_____
   f. CO_2_____
   g.
   h.
3. Helium Purity (ppm) Ⓦ Spot Check
   H_2O_________
   O_2_________

TOTAL WEIGHT

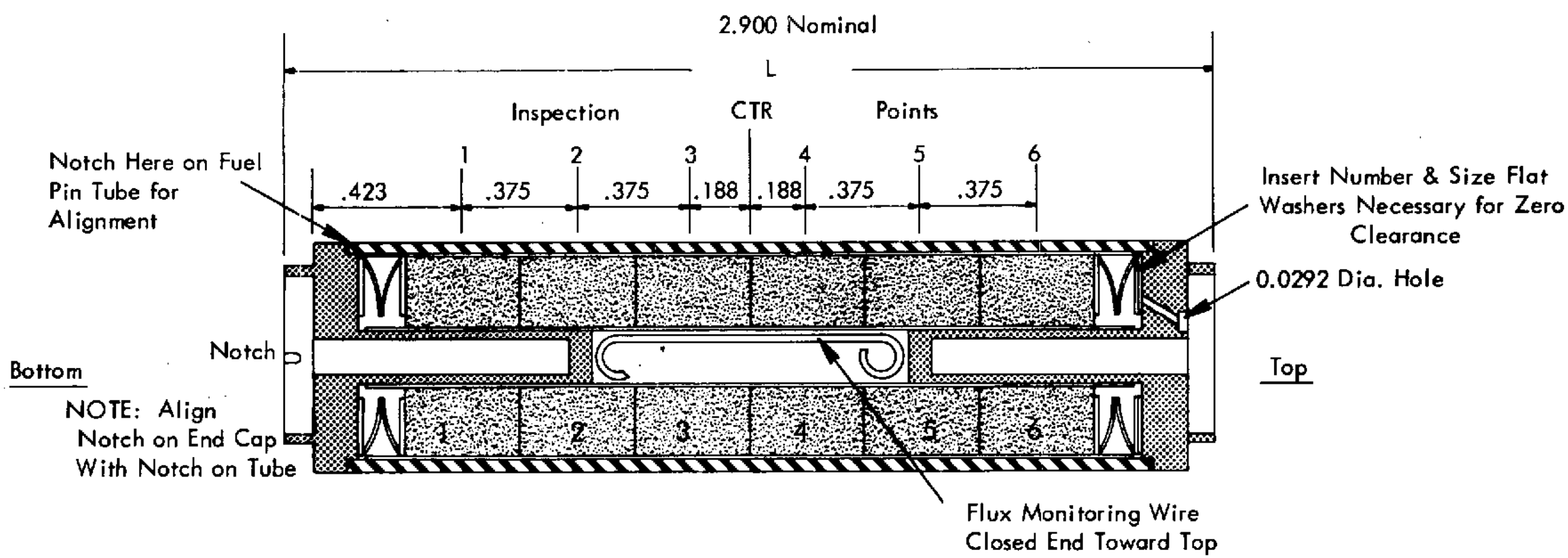
Sect. B. Fuel_____________
C. Clad_____________
D. Liner_____________
E. End Caps_____________
F. Spacers_____________
G. Washers_____________
H. T.C. Protect Tube_____________
Flux Wire_____________
Total_____________

J. Inspection

1. Visual_________________ Date_________________ Initial_____________
2. Ident. No._________________ Date_________________ Initial_____________
3. Helium Leak Check_________ Date_________________ Initial_____________
   Standard Leak Rating_____________ Leak Detector Scale Reading_____________
   Test Chamber Empty Scale Reading_________ With Fuel Pin_____________
4. Dye Penetrant_________________ Date_________________ Initial_____________
5. X-ray_________________ Date_________________ Initial_____________

FUEL PIN

Ident. No.________________



APPENDIX B

PRE-IRRADIATION CAPSULE DATA

PRE-IRRADIATION CAPSULE DATA

A. Capsule Data   Date Completed__________

1. Capsule Identification No. ______________
2. Fuel pin identification No. ______________
3. Size designation D D/2 ______________
4. Assembly designation X Y ______________
5. Capsule assembly weight excluding thermocouples______________

B. Capsule Dimensions

1. Capsule Length "A"______________
2. Between TC bend & bottom end cap "B"______________
3. Outside end of bottom thermowell to thermocouple junction "C"______________
4. Outside end of top thermowell to thermocouple junction "D"______________
5. Clearance between top fuel pin spacer and end cap "E"______________
6. Length of spring (Part 15)______________

C. Capsule Tube Dimension (Tube Ⓦ Identification No.__________) Part No. 5

1. I.D. at fuel area Pos. "F" 0^{o}_____ 90^{o}_____
2. I.D. at fuel area Pos. "E" 0^{o}_____ 90^{o}_____
3. I.D. at fuel area Pos. "G" 0^{o}_____ 90^{o}_____

D. Helium Gap between Fuel Pin and Capsule

1. Pos. "F" Difference in fuel pin OD & capsule ID______________
2. Pos. "E" Difference in fuel pin OD & capsule ID______________
3. Pos. "G" Difference in fuel pin OD & capsule ID______________

E. Capsule Closure

1. Helium pressure (psia)______________ Temperature, °F________________

2. Helium purity (ppm) (From supplier certification).

   a. H_2______
   b. H_2O______
   c. N_2______
   d. O_2______
   e. CO_2______

3. Helium purity (ppm) Ⓦ spot check.

   O_2______
   H_2O______

F. Thermocouples

Identification No.			
Location	Top (Well)	Bottom (Well)	Bottom (End cap)
Type			
Insulation (Hot Zone)			
(Cold Zone)			
Grounded or Ungrounded			
Junction Location From Mid Capsule			
Resistance			
Sheath to Positive wire			
Sheath to Neg. wire			
Wire to Wire			
Braze Alloy Used			
Cold End Seal			

G. Parts Identification

1. Top end cap (Part No. 1) Ⓦ Identification No.__________
2. Bottom end cap (Part No. 2 __________
3. Top fuel pin spacer (Part No. 6) __________
4. Bottom fuel pin spacer (Part No. 6) __________
5. Top thermowell (Part No. 7) __________
6. Bottom thermowell (Part No. 8) __________

H. Inspection

1. Visual__________ Date__________ Initial__________
2. Ident. No.__________ Date__________ Initial__________
3. Helium leak check ____ Date__________ Initial__________
   Std. Leak Rating________ Scale Reading with Std. Leak__________
   Calibration________ Background Empty Chamber__________
   With Capsule in Chamber__________
4. Dye penetrant ________ Date__________ Initial__________
5. X-ray__________ Date__________ Initial__________
6. Thermocouple 1000°F Calib.________ Date__________ Initial__________

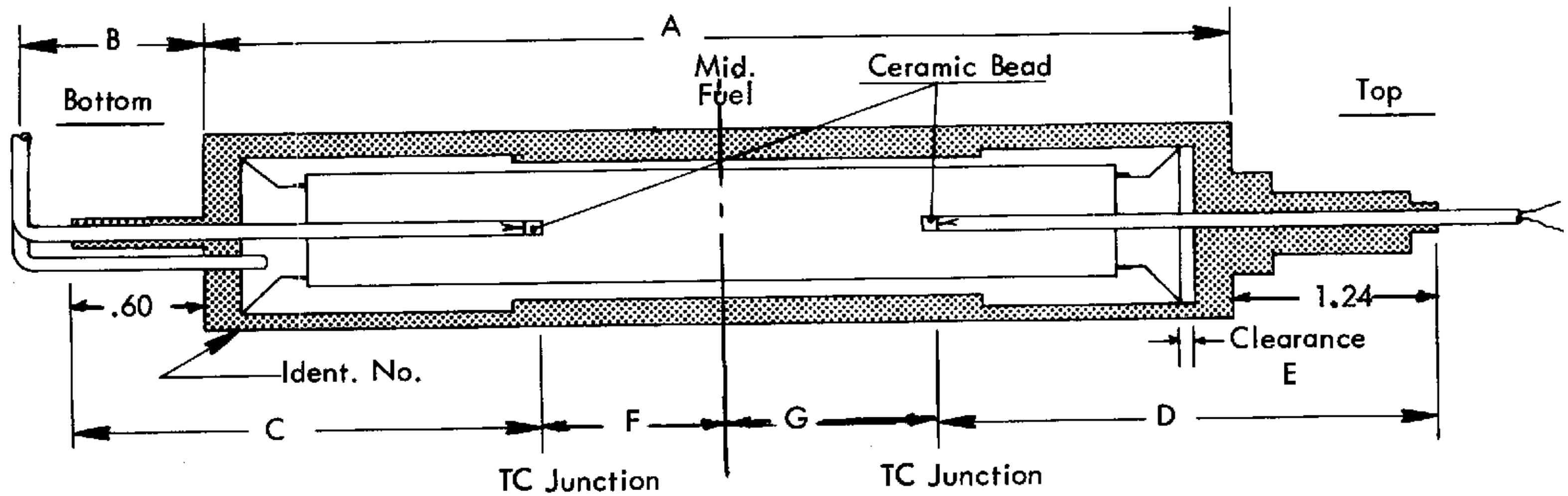
Thermocouple Calibration Check

Temp., $^{\circ}$F	Top TC No.	Bottom TC in Well No.	Bottom TC in End Cap No.	Ref. TC
Room				
500				
1000				

CAPSULE ASSEMBLY

Capsule Ident. No. 901-____________

Fuel Pin Ident. No.________________



Mid Fuel from Bot. = A/2-.040

Mid Fuel from Top = A/2+.040

Dimension	Measurement
A	
B	
C	
D	
E	
F	
G	

APPENDIX C

FUEL PIN ASSEMBLY CHECKOFF

FUEL PIN ASSEMBLY CHECKOFF

I. PREPARATION

Initial

________ 1. Fuel Pin I.D. No.____________

________ 2. Select the following parts and verify complete material certification inspection record.

____ a. 1 ea. - Part No. 3 - Fuel Pin End Cap (Without Hole) I.D. No.______

____ b. 1 ea. - Part No. 3 - Fuel Pin End Cap (With Hole) I.D. No.______

____ c. 1 ea. - Part No. 4 - Fuel Pin Tube I.D. No.______

____ d. 1 ea. - Part No. 9 - Thermocouple Protective Tube I.D. No.______

____ e. 1 ea. - Part No. 10 - Tungsten Liner I.D. No.______

____ f. 6 ea. - Part No. 14 - UN fuel pellets (Bottom) 1 I.D. No.______

2 I.D. No.______

3 I.D. No.______

4 I.D. No.______

5 I.D. No.______

(Top) 6 I.D. No.______

____ g. 8 ea. - Part No. 11 - Washer 4 ea. .005) (2 each)
4 ea. .003) Spare but may be needed.

____ h. 4 ea. - Part No. 12 - Spherical Spacer

____ i. 1 ea. - Part No. 16 - Flux Monitoring Wire

________ 2A. Complete Necessary Sections of Pre-Irradiation Fuel Pin Data Sheets

________ 3. Clean parts a thru i above using cleaning procedure section of this checkoff. Note: All cleaning is to be accomplished as near to time of use as practical.

________ 4. Clean storage containers as specified under cleaning procedure section of this checkoff.

________ 5. Clean OD of fuel shipping container per cleaning procedure section of this checkoff.

________ 6. Slide (Part 10) tungsten liner into (Part 4) Fuel pin tube.

________ 7. Load tungsten flat washers and spherical spacers onto bottom and top end caps.

________ 8. Load parts for one fuel pin into glove box.

________ 9. Load clean fuel pin assembly mandrels and measuring instruments into glove box.

________ 10. Load clean handling tools and welding fixtures into glove box.

II. PUMPDOWN

________ 1. Evacuate Glove box to at least 5×10^{-5} torr. Press ________

________ 2. Backfill glove box with UHP helium to 1 atmosphere

________ 3. Open fuel container and make visual check of fuel and spot check O.D. and I.D. and length measurements of pellet No. 2 and 4 to compare with measurements supplied by ORNL.

Remarks: ________

________ 4. Evacuate glove box to the 10^{-6} range while heating chamber to $\sim 200^{\circ}$F with heating lamps. TEMP. ________ PRESSURE ________

________ 5. Backfill with UHP helium to atmosphere press

________ 6. Monitor and record O_2 and H_2O level in glove box. O_2 ________ H_2O ________

Fuel Pellet Measurement in (3) Above

Fuel Pellet No.	O. D.	I.D.	Length

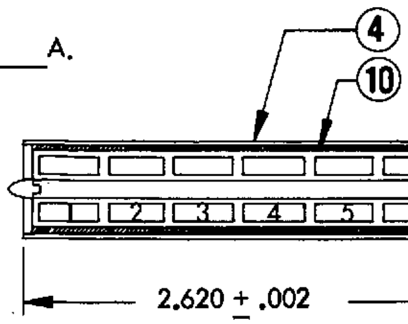
III. FUEL PIN ASSEMBLY

Initial

_____ A.

Fuel Pin Tube .375 OD .318 ID x 2.620 ±.002 Lng

Tungsten Liner .311 ID .318 OD x 2.498 Lng

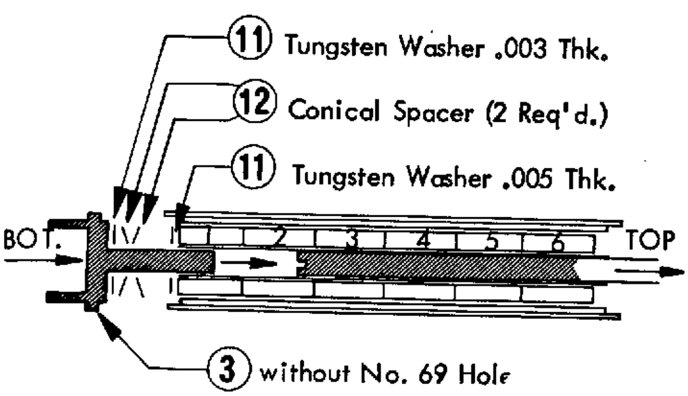


_____ 1. Insert stepped mandrel into top of fuel pin tube tungsten liner subassembly.

_____ 2. Insert part No. 14 fuel pellets one at a time into fuel pin tube-tungsten liner subassembly.

_____ 3. Insert part No. 9 thermocouple protective tube into center hole of fuel.

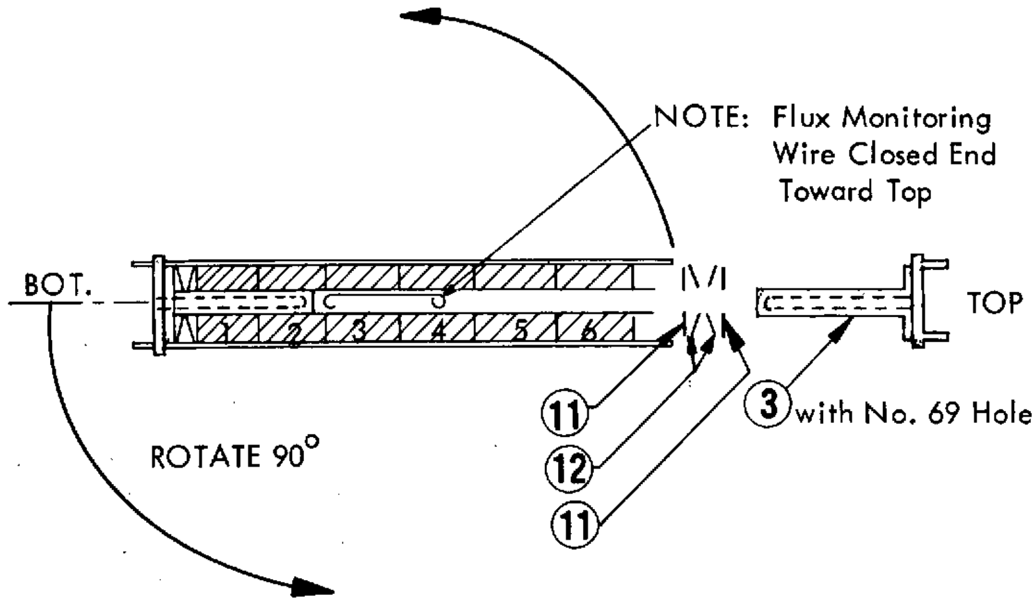
_____ B.



Assemble bottom end cap - washer subassembly with fuel pin subassembly. Note: align end cap slot with fuel pin tube inspection notch.

Initial

_______C.



_______1. Place sub-assembled unit in vertical position with Item 3 base down.

_______2. Remove mandral end adapter.

_______3. Insert flux monitoring wire (Part No. 16). Closed end toward top.

_______4. Carefully insert fuel pin end cap Part No. 3. With No. 69 hole.

NOTE: Use as many Part 11 washers as necessary to make assembly fit together without slop.

Spacers (Part No. 12)

Location	No. Spacers	Thickness	Height
Top			
Bottom			

Washers (Part No. 11)

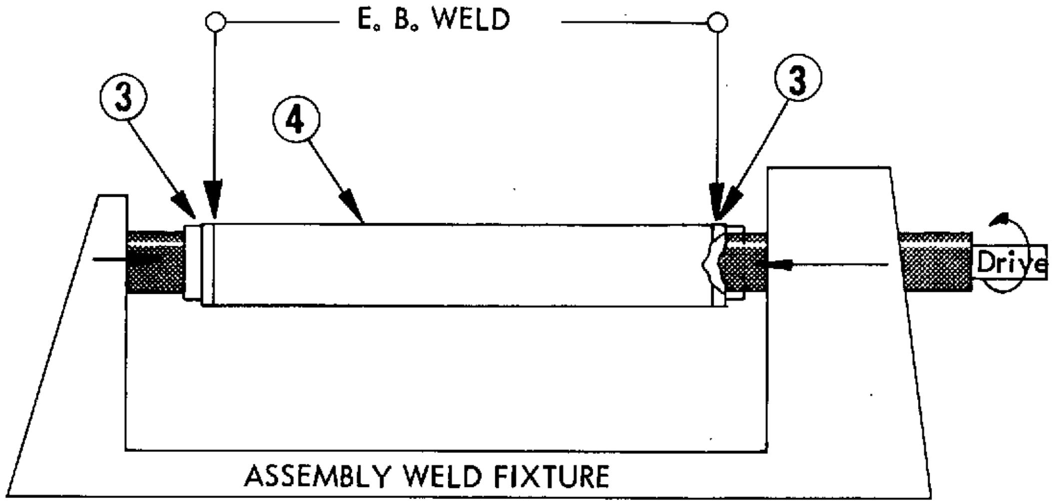
Location	No. Washers	Thickness
Top next to fuel		
Top next to end cap		
Bottom next to fuel		
Bottom next to end cap		

_______ Measure Length of fuel pin before welding_______

_______Measure length of fuel pin after welding_________

Initial

______ D.



______ 1. Load assembled device (fuel pin assembly) into E.B. weld fixture, locating on centers with adapters that fit in fuel pin end caps ID and thermocouple well chamfer. Note: Align notch in end cap with notch on fuel pin tube.

______ 2. Adjust compression on weld fixture. (Spring loaded to accommodate thermal strain during welding).

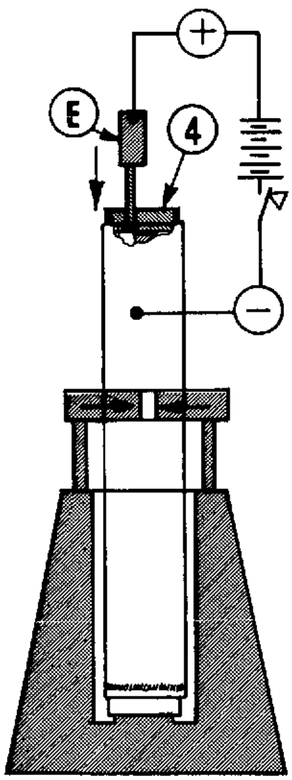
______ 3. Evacuate weld chamber to 5×10^{-5} torr. Record pressure______________. Weld end caps Item 3 to fuel pin tube Item 4.

______ 4. Backfill chamber to atmospheric pressure with UHP helium.

______ 5. Visually inspect end cap welds.

Initial

______ E.



SEAL FIXTURE

______ 1. Position fuel pin tube in seal weld fixture.

______ 2. Record Chamber O_2_____ & H_2O_____. Must be less than 5.0 ppm O_2 & 5 ppm H_2O before proceeding.

*______ 3. Record temp.________ and pressure________ in chamber.

______ 4. Make seal weld.

______ 5. Visually inspect seal weld.

*The following fuel pins were sealed while entire fuel pin was preheated to ~600°F: D-0, D-1, D-3, D-5, D-2, D-7, 504A, 504B, 503A, 503B, and 503C.

IV. INSPECTION

Initial

__________ 1. Remove sealed fuel pin from weld chamber and immediately helium leak check fuel pin.

_____ a. Leak detector calibration
Std. Leak Rating______ Scale Reading with Std. Leak_______
Calibration______ Background Empty Chamber________
With Fuel Pin Chamber___________

_____ b. Result of leak test

__________ 2. Visually inspect fuel pin welds. Result______________________________

__________ 3. Check NASA identification number on bottom end plug.

__________ 4. Dye penetrant inspect fuel pin welds. Top end cap_____ Bot. End cap______
Seal______

__________ 5. Measure length of fuel pin____________________

__________ 6. Weigh fuel pin____________________

__________ 7. X-ray fuel pin. 0° & 90°

DATE______________________

SIGNED____________________

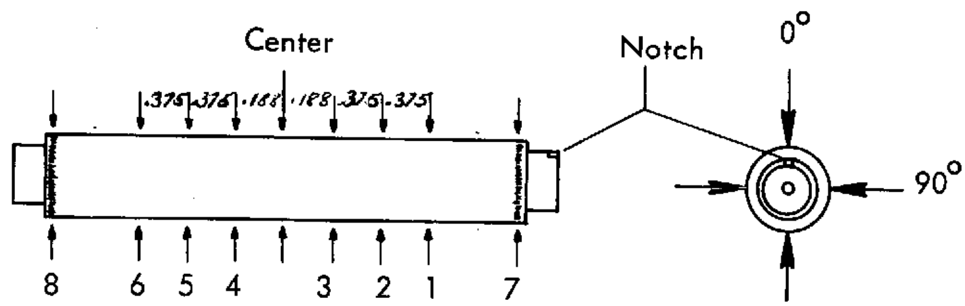
REMARKS:____

FUEL PIN MEASUREMENT AFTER ASSEMBLY

Fuel Pin ID No.______________

Date____________

Initial__________



OD Measurements

Position	0°	90°
1		
2		
3		
Center		
4		
5		
6		
7		
8		

APPENDIX D

CAPSULE ASSEMBLY CHECKOFF

CAPSULE ASSEMBLY CHECKOFF

I. PREPARATION

Initial

______ 1. Capsule Identification No.______________

______ 2. Select the following parts and verify complete material certification & inspection records. (Part No's refer to Dwg. 352462-1 & 352463-1).

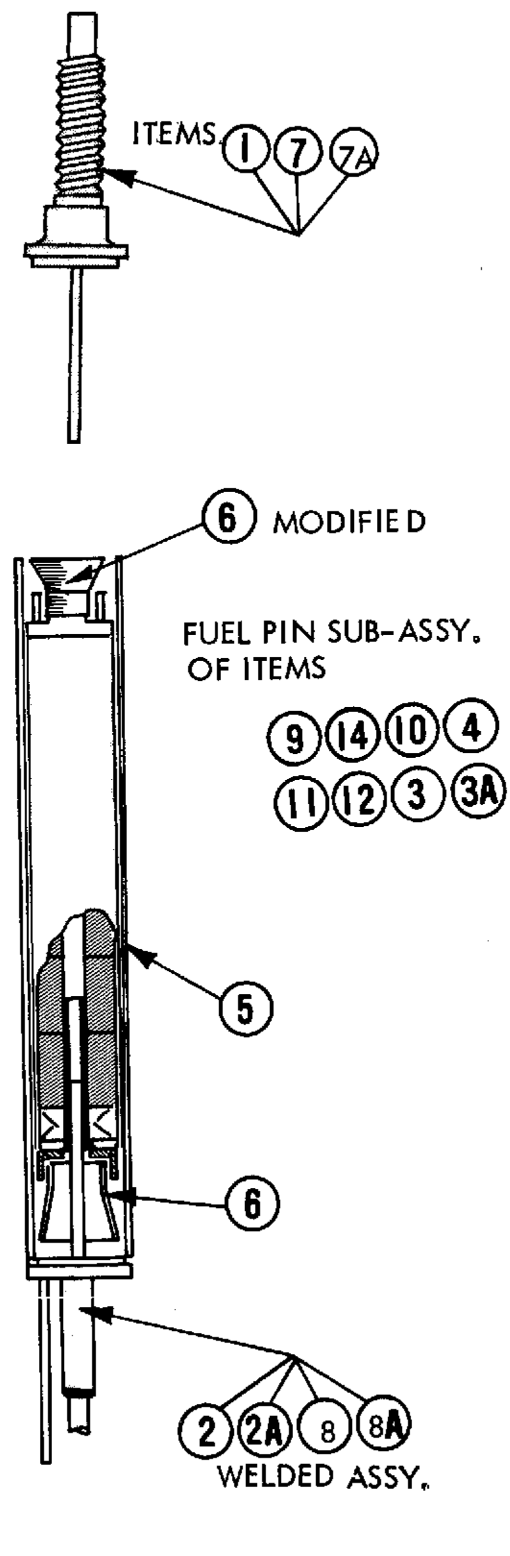
______ a.	Fuel Pin	I.D. No.______
______ b.	Capsule end cap (top) Part No. 1	I.D. No.______
______ c.	Capsule end cap (bottom) Part No. 2	I.D. No.______
______ d.	Capsule tube (Part No. 5)	I.D. No.______
______ e.	Fuel pin spacer (Part No. 6) 2 ea.	I.D. No.______
		I.D. No.______
______ f.	Thermocouple well (Part No. 7) (Preassembled)	I.D. No.______
______ g.	Thermocouple well (Part No. 8) (Preassembled)	I.D. No.______
______ h.	Thermocouple (Part 13) 2 ea.	I.D. No.______
______ i.	Thermocouple (Part 17) "D" size only	I.D. No.______
______ j.	Spring (Part No. 15)	I.D. No.______

______ 3. Clean parts a,b,c,d,e,i,&j above in accordance with cleaning procedure section of this checkoff. NOTE: All cleaning is to be accomplished as near to time of assembly as practical.
Parts No. f, g & h must have additional special cleaning procedure as follows:

(a) Parts f & g ID and OD to be cleaned according to cleaning procedure before sub-assembly. After sub-assembly only OD is to be cleaned and entire thermocouple well including Ta piece to be cleaned by SS procedure.

(b) Thermocouple sheath (length that will be in furnace) or capsule to be rinsed with alcohol before installing. The only cleaning of ceramic will be bakeout firing in vacuum.

ASSEMBLY



ITEMS
1
7
7A
6
MODIFIED
FUEL PIN SUB-ASSY.
OF ITEMS
9
14
10
4
11
12
3
3A
5
6
2
2A
8
8A
WELDED ASSY.

II. ASSEMBLY

Initial

_____ 1. TIG weld .032 dia. stainless steel wire to bot. end cap (Part No. 2)

_____ 2. Assemble fuel pin with fuel pin spacers into capsule tube and set up in tack weld fixture.

_____ 3. EB tack weld fuel pin spacers to fuel pin.

_____ 4. Test assemble bottom end cap with capsule subassembly and measure distance from top of fuel pin spacer to top of capsule tube.

a. From top of fuel pin _____________

b. From top of fuel pin spacer _____________

_____ 5. Measure penetration of top end cap into capsule tube _____________

_____ 6. Subtract 5 from 4a _____________ to determine spring length required.

_____ 7. Subtract 5 from 4b _____________ to determine clearance.
Note: If clearance is not .040 ± .005 machine end cap to make correct clearance.

_____ 8. Remove bottom end cap from capsule subassembly.

_____ 9. Construct top thermocouple well (Part No. 7) subassembly and leak check.

_____ 10. Construction bottom thermocouple (Part No. 8) subassembly and leak check.

_____ 11. Insert a beryllia bead 0.050 long into thermocouple well (Part 7) on "D" size insert alumina sleeve over TC junction, then insert thermocouple (Part 13) into well so that junction is positioned 1/16" from beryllia bead. Distance from outside end of thermocouple well to junction _____________
Note: Check resistance thermocouple to sheath and if it drops below 7×10^8 ohms ft., remove and correct.

_____ 12. EB weld thermocouple into top thermocouple well.

_____ 13. EB weld thermocouple/thermocouple well subassembly into top end cap.

______14. Leak check top end cap subassembly by pressurizing with helium for 30 min. at 3 atmospheres, remove from pressure and immediately bubble check in grain alcohol then mass spec. leak check.
Std. Leak____________ Scale____________ Calib.____________
Leak Rate____________

______15. Insert beryllia bead and thermocouple into thermocouple well (Part 8) the same as in Part 7 above. Distance from outside end of thermocouple well to junction ____________

Note: Check resistance thermocouple to sheath and if it drops below 7×10^8 ohms ft., remove and correct.

______16. EB weld thermocouple into bottom thermocouple well.

______17. EB weld thermocouple/thermocouple well subassembly into bottom end cap.

______18. On "D" size capsule EB weld collar on 1/16" dia. gas sensing thermocouple.

______19. On "D" size capsule EB weld collar of gas thermocouple into bottom thermocouple.

______20. Leak check bottom end cap subassembly by pressurizing in helium for 30 min. at 3 atmospheres pressure. Remove from pressurizing chamber and immediately bubble check in grain alcohol then mass spec. leak check. Leak Rate____________
Std. Leak____________ Scale____________ Calib.____________

______21. Install bottom end cap-thermocouple subassembly in welding fixture and top end cap-thermocouple subassembly in tail stock fixture.

______22. Install bottom of fuel pin capsule tube into bottom end cap.

______23. Position spring (Part No. 15) on top of fuel pin inside fuel pin spacer.

______24. Carefully insert top capsule end cap - thermocouple well subassembly into capsule.

______25. EB weld top and bottom end cap to capsule tube.

a. Visual inspect weld. Result________________________

III. SEALING CAPSULE

Initial

_____ 1. Position capsule tube in seal weld fixture.

_____ 2. Record Chamber O_2_________ & H_2O_________. Must be less than 5.0 ppm O_2 & 5 ppm H_2O before proceeding.

* _____ 3. Record temperature__________ and pressure_________ in chamber.

_____ 4. Make seal weld.

IV. INSPECTION

Initial

_____ 1. Remove sealed capsule from chamber and immediately mass spectrometer leak check.

a. Leak detector calibration_________

Std. leak rating_________ Scale reading with std. leak_________

Background empty chamber_________ With capsule in chamber_________

b. Result of leak test____

_____ 2. Visually inspect capsule seal and end cap welds. Result_____________________

_____ 3. Dye penetrant inspect seal and end cap welds. Result_____________________

_____ 4. Weight capsule assembly_________

_____ 5. All capsules install (2) hafnium discs over TC at bottom of capsule then bend thermocouples to the dimensions specified on NASA Dwg. CD-352462-1 and CD-352463-1.

*The following entire capsules were preheated to ~600°F before sealing:
901-D2, 901-D7, 901-504A, 901-503A.

_____ 6. Measure capsule length between flats of end caps_______________

_____ 7. Measure distance between bottom thermocouple bend and bottom end cap flat_______

_____ 8. X-ray capsule longitudinal view 0° and 90°.

_____ 9. Run capsule thermocouple check at 500°F and 1000°F in a purged inert atmosphere.

Temperature $^{\circ}$F	Top T. C.	Bottom T. C. in Well	Bottom T.C. in End Cap	Ref. T. C.
Room				
500				
1000				

_____ 10. Pressurize capsule in helium at 3 atmospheres for 30 min. mass spec. leak check.

Std. leak rating_________Scale_________

Background empty chamber_________With capsule_________

Leak rate_________

DATE_______________

SIGNED_______________

REMARKS_______________

APPENDIX E

THERMOCOUPLE CONSTRUCTION

Thermocouple Leads

All thermocouples with the exception of the 4 fuel center thermocouples installed in capsules 901-502B and 901-504D were supplied by NASA Lewis and manufactured to NASA Specification C-405955. A description of these are given on Drawing 352462-1 and 352463-1. Some of the "D" size thermocouples were redrawn or swaged in the hot zone to reduce the wire size from .016" to .013" to make fitting of the alumina insulator over the wire possible. This was necessary because of a manufacturing error which resulted in delivery of the larger size wire. The 4 fuel center thermocouples installed in capsules 901-502B and 901-504D were completely manufactured by the Westinghouse Astronuclear Laboratory to NASA Dwg. CD-352463-1 and applicable sections of WANL Equipment Specification 675502-B* and to the following requirements:

Type - Chromel/alumel
Overall Length - 32.0 ft, OD - .125"
No. of Wires - 2
Wire diameter - $.020 {}^{+.002}_{-.000}$
Sheath Material - 304 stainless steel
Sheath Wall Thickness - .025"
Insulation Cold Zone - alumina min. purity 99.5%
Insulation Hot Zone - alumina .072" OD with two .023" dia. holes
Cold End Seal - Epoxy resin
*NASA T/C^s argon purged prior to drawing; WANL T/C^s not argon purged.

Hot Zone Fabrication for All Thermocouples

All thermocouples were visually inspected for appearance and finish and the length and diameter of each was checked for conformance to specification. Approximately 1.0" of the sheath was stripped back at the cold end and the end of the sheath was sealed with epoxy resin (Hysol No. 0151 clear). The sheath was stripped back ~2.5" on the other end and resistance measurements were made and recorded on the "Thermocouple Fabrication Inspection" Sheet attached. All insulation resistance measurements were made at 50 Vdc with a Freed megohmmeter model 1020-C and wire resistance was measured with a Honeywell Wheatstone Bridge Model 1071.

Exposed thermocouple wires were examined at 7X for cracks or gouges and any questionable area was checked at 30X with a stereomicroscope. The hot zone ceramic was vacuum fired at ~2000°F for 2 hours before assembly and all assembly was accomplished in a clean room with relative humidity controlled below 25%. Thermocouple wire and ceramic insulation was handled only with clean lint free gloves or clean tools at all times. The ceramic insulator was inserted over the wires and the hot junction was constructed as follows:

1. Thermocouple wire was clamped in a copper heat sink with ~.010" protruding.
2. Electrode of a "Dynatech Corp." model 216 Ng welder with extension welding head was positioned ~.060" above thermocouple.
3. Welding controls were set.

   Weld time - minimum
   Weld current - minimum
   Pre-purge - 50%
   Post-purge - 50%
   } Ultrapure argon used.
4. Weld was made.

Thermocouple bead was inspected at 7X for cracks, pits and necking of wire. Resistance measurements were made and recorded on the "Thermocouple Fabrication Inspection Sheet". Resistance measurements were required to meet NASA Specification C-405955 or thermocouple was rejected.

Thermocouples were stored in an evacuated or inert atmosphere until ready for use. Figures E-1, E-2, E-3 and E-4 are photographs of the hot junction ends of thermocouples. The final operation before thermocouple hot end was sealed into the thermocouple well was a 1400°F bakeout. Three to four feet of the thermocouple hot end was inserted into the hot zone of a vacuum pumped hot wall furnace and baked for 4 hours at 1400°F in 5×10^{-5} torr vacuum or better. The thermocouples were cooled to room temperature and the furnace was backfilled with high purity argon. The thermocouple was removed from the furnace and inserted in the thermocouple well as fast as practical (usually within 15 minutes) and was either brazed or welded in place in accordance with the capsule assembly checkoff procedure. Resistance measurements were made after the thermocouple was sealed into the thermocouple well.

TC No.________

THERMOCOUPLE FABRICATION INSPECTION

A. Before making hot junction:

1. Wire resistance negative lead(s) ____________
2. Wire resistance positive lead(s) ____________
3. Insulation resistance negative lead(s) to sheath ____________
4. Insulation resistance positive lead(s) to sheath ____________
5. Insulation resistance positive to negative lead(s) ____________

B. After making hot junction:

1. Wire resistance of thermocouple loop(s) ____________
2. Insulation resistance of thermocouple loop(s) to sheath ____________
3. Visual inspection at 7X of thermocouple wires where stripped back for cracks and gouges > .001 ____________
4. Visual inspection at 7X of thermocouple junction for cracks and reduction of wire diameter. ____________

Date________________ Signed____________________________

Remarks____

____

____

____

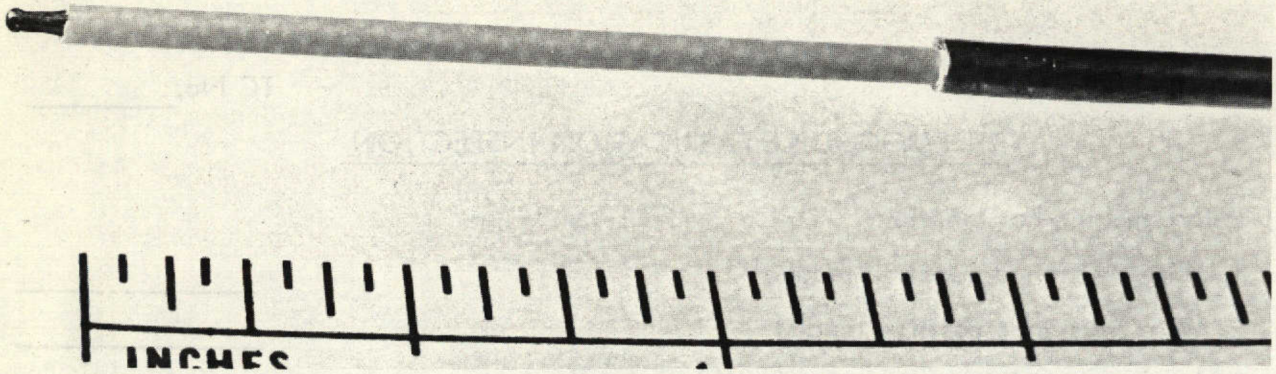
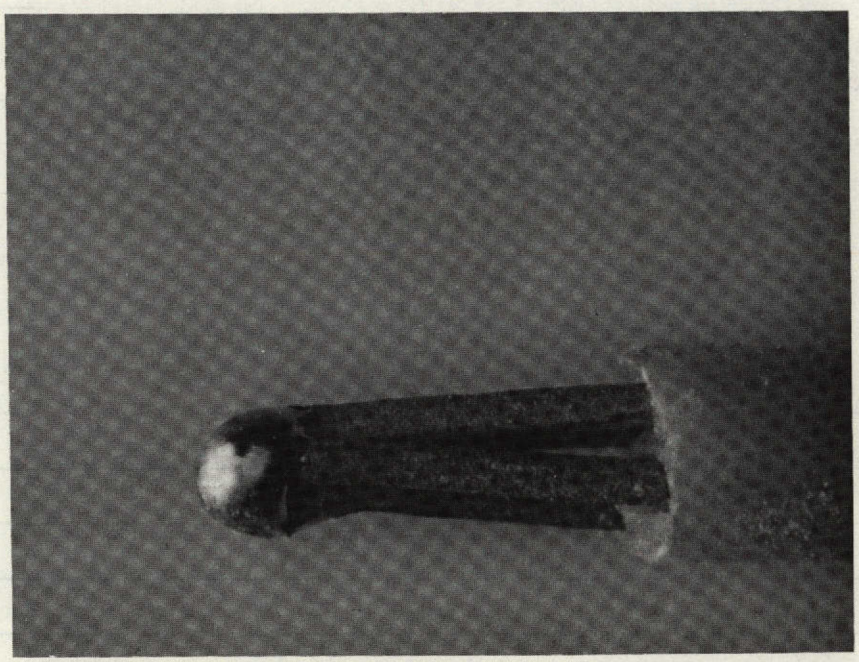


Figure E-1. 3/32" Diameter 4-Wire Fuel Center Thermocouple Hot Zone Construction



19X

Figure E-2. 3/32" Diameter 4-Wire Thermocouple Hot Junction

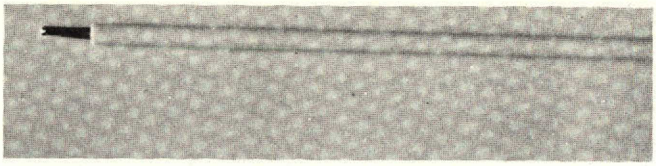
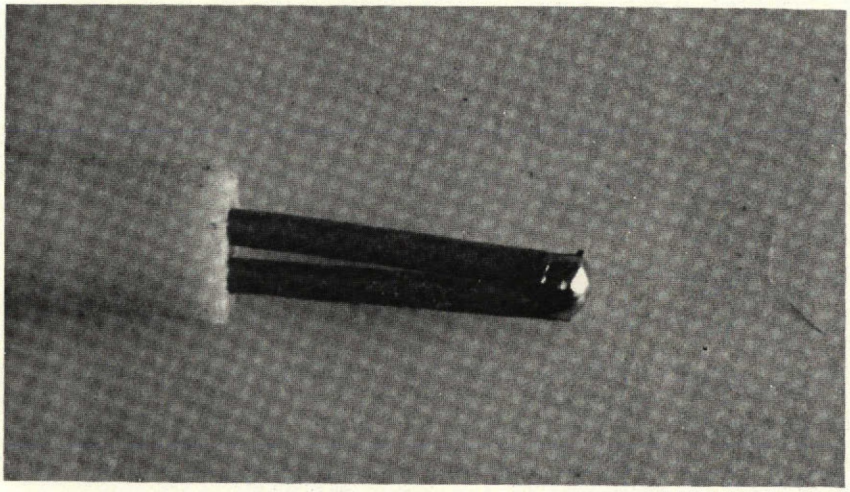


Figure E-3. 1/16" Diameter 2-Wire Fuel Center Thermocouple Hot Zone Construction



19X

Figure E-4. 1/16" Diameter 2-Wire Thermocouple Hot Junction

APPENDIX F

INSPECTION PROCEDURES

1. Liquid Penetrant Inspection (Dye Penetrant)

   Liquid penentrant inspection was performed to WANL Process Specification 294564 Revision No. 4 to the general acceptance level of Class 00. A copy of this specification is attached.

2. Ultrasonic Inspection

   Ultrasonic inspection was performed to MIL-STD-271D (Ships) Paragraph 7 with the general rejection level of indications greater than 5% of wall thickness.

3. Helium Leak Testing

   Helium leak testing was performed to MIL-STD-271D (Ships) Paragraph 6 and WANL Process Specification 294502 Revision No. 1. Maximum allowable leak rate was 5×10^{-7} std. cc/sec. A copy of process specification 294502 Rev. 1 is attached.

4. Radiography

   Radiography was performed to MIL-STD-271D (Ships) Paragraph 3. Acceptance was based on examination and review by the Westinghouse Project Engineer and the NASA Project Engineer.

5. Visual

   Visual inspection was normally performed at 1-7X magnification with criteria for acceptance based on specifications in applicable drawings and procedures, general appearance and lack of anomalies.

6. Dimensional

   All capsule and fuel pin machined parts were 100% dimensionally inspected and parts that did not meet drawing requirements were rejected. In addition dimensions of each fuel pin tube ID and OD was recorded to the nearest .0001" at 7 axial locations in 2 radial positions 90° apart. All capsule tube dimensions were recorded to the nearest .0001" at 5 axial locations in 2 radial positions 90° apart. ID measurements were made with a 3 prong inner micrometer. After assembly each fuel pin OD was measured and recorded at 9 axial locations in 2 radial positions 90° apart and at the same time with the same micrometer the same inspector measured and recorded measurements from a standard which was delivered to NASA for future reference. All micrometers and other inspection equipment is periodically calibrated to insure continued accuracy.

INFORMATION CATEGORY

UNCLASSIFIED

R. Sollanberger 5/14/65
Authorized Classifier Date

Westinghouse Electric Corporation

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PROCESS SPECIFICATION 294564 Revision No. 4
(Not for Publication)

June 13, 1968

LIQUID PENETRANT INSPECTION

1. SCOPE

This specification covers requirements for liquid penetrant inspection, designated as follows:

Designation	Description*
294564-1	Method using solvent-removable visible dye penetrant and a penetrant remover (solvent).
294564-2	Method using postemulsifiable visible dye penetrant and an emulsifier.
294564-3	Method using water-washable visible dye penetrant.
294564-4	Method using water-washable fluorescent penetrant.
294564-5	Method using postemulsifiable fluorescent penetrant and an emulsifier.
294564-6	Method using a high intensity postemulsifiable fluorescent penetrant and an emulsifier.

NOTE: Unless otherwise specified, the following requirements apply to all designations.

2. APPLICABLE DOCUMENTS

The following documents, of the issue in effect on the date of invitation for bids, shall form a part of this specification to the extent specified herein.

MIL-STD-23 PS 294584

* Acceptance standards are to be selected from Tables I and II herein.

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POP/eh

W form 59504A

3. REQUIREMENTS

3.1 SAFETY PRECAUTIONS

3.1.1 Penetrant materials shall not be over 100°F and shall not be applied to a surface which is at a temperature greater than 100°F.

3.1.2 Due to the flammable nature of liquid penetrant inspection materials, open flame shall not be used for heating purposes.

3.1.3 (294564-1): Highly volatile solvents shall be used cautiously. Their vapors are relatively toxic and the liquid is a primary skin irritant. Extreme care shall be exercised in handling the volatile solvents as many of them are highly inflammable liquids.

3.2 SUPPLEMENTARY REQUIREMENTS: Areas to be tested and the kind of liquid penetrant, identified by dash number, shall be specified in applicable drawings, specifications, contracts or the purchase order. Penetrant test markings incorporated in drawings shall be in accordance with MIL-STD-23.

3.3 QUALIFICATION

3.3.1 Personnel: Personnel performing and interpreting liquid penetrant tests shall be certified according to PS 294584 when specified by the purchase order.

3.3.2 Equipment Requirements: The test equipment in the hands of qualified nondestructive test personnel shall be capable of consistently obtaining results of specified quality level and shall conform to the applicable requirements of PS 294584 when specified by the purchase order.

3.4 SURFACE PREPARATION

3.4.1 Surface Condition: Surfaces to be inspected shall be free from scale, slag, and adhering or embedded sand or other extraneous materials.

3.4.2 As-Welded Surfaces: As-welded surfaces shall be considered suitable for liquid penetrant inspection without grinding, if the slag is removed and surface irregularities do not interfere with interpretation of the test results and if the weld contour blends into the base metal without undercutting.

3.4.3 Surface Blasting: Shot, sand, grit and vapor blasting shall not be done on surfaces which are to be liquid penetrant inspected unless specifically approved by the purchaser.

3.4.4 Finished Surfaces: Surfaces, for which a specific finish is required, shall be given this surface finish prior to the final liquid penetrant inspection prescribed by the applicable specifications. Inspection at intermediate stages of fabrication shall be permitted.

3.4.5 Cleaning: All surfaces being tested shall be thoroughly cleaned of extraneous material. If a nonvolatile liquid is used for cleaning, the surface shall be heated or dried with hot air to assure complete removal of the cleaner. As a final cleaning operation, each surface shall be dipped, sprayed, wiped, or brushed with trichloroethylene, perchloroethylene, acetone, or methyl chloroform and thoroughly dried by removing the excess with a clean, dry cloth or absorbent paper, and allowing the remainder to evaporate for a minimum of five minutes. Prior to liquid penetrant inspection, the surface to be tested and any adjacent area within one inch of the surface to be tested shall be dry and free of any dirt, grease, lint, scale and salts, coatings, or other extraneous matter that would obscure surface openings or otherwise interfere with the test.

3.4.6 Temperature: Maximum penetration into extremely small openings requires that the penetrant and the test surface be maintained at the temperature recommended by the penetrant manufacturer but in no case shall be less than 50°F.

3.5 LIGHTING IN TEST AREA

3.5.1 Visible Penetrants (294564-1, -2, and -3): **When visible dye penetrants are used, the test area shall be adequately illuminated for proper evaluation of indications revealed on the test surface.**

3.5.2 Fluorescent Penetrants (294564-4, -5, and -6): When a fluorescent penetrant is used, the inspection shall be accomplished in a darkened area using ultraviolet lamp with a brilliance of 90 foot candles minimum, when measured in the center of the beam at a distance of 15 inches from the lamp using an unfiltered Weston Model 703 light meter, or equal. A minimum of 5 minutes shall be allowed for the lamp to obtain full brilliance before beginning the inspection. This equipment shall be maintained and calibrated in a manner to ensure reliable and uniform operation. This inspection shall be performed at least once a week.

3.6 PROCEDURE ON PENETRANTS

3.6.1 Application: The surface to be tested shall be thoroughly and uniformly coated with penetrant by flooding, brushing, immersing or spraying. The surface shall be kept wetted for the time specified as follows for the method employed:

Penetrant Designation	Min. Penetration Time	Max. Penetration Time
294564-1	15 minutes	20 minutes
294564-2	15 minutes	20 minutes
294564-3	25 minutes	30 minutes
294564-4	25 minutes	30 minutes
294564-5	15 minutes	20 minutes
294564-6	10 minutes	15 minutes

3.6.2 Removal of Penetrant:

3.6.2.1 (294564-1) Solvent Removable: Flushing of the surface with any liquid following application of the penetrant and prior to developing shall be prohibited. The excess penetrant shall be removed from all surfaces as follows:

(a) As much excess penetrant as possible shall be removed by first wiping the surface thoroughly with a clean, dry cloth or absorbent paper.

(b) The remaining excess penetrant shall be removed by wiping the surface with a clean cloth dampened with a penetrant remover. Acetone shall not be used to remove excess penetrant.

3.6.2.2 (294564-3 and -4) Water Washable: The penetrant shall be removed from all surfaces by swabbing with a clean, lint-free cloth saturated with clear water or by spraying with water not exceeding 120°F and 40 psi line pressure.

3.6.2.3 Postemulsifiable:

3.6.2.3.1 (294564-5 and -6): The emulsifier shall be applied either by immersing, flooding or spraying of the part. After a suitable penetration time (See Section 3.6.1) and emulsification period the surface film of the penetrant and emulsifier shall be removed from the part by employing a hot water spray not exceeding 120°F amd 40 psi. After washing, all surfaces shall be checked under a black light to insure complete cleaning of all surfaces. Alternatively, the penetrant shall be removed by use of the cleaner specified by the manufacturer of the penetrant.

3.6.2.3.2 (294564-2): The procedure shall be according to Section 3.6.2.3.1 except that after washing, all surfaces shall be checked under adequate visible light to insure complete cleaning.

3.6.3 Surface Drying:

3.6.3.1 Solvent Removable Penetrants (294564-1): The drying of test surfaces, after the removal of the excess solvent removable penetrant, shall be accomplished only by normal evaporation, or by blotting with absorbent paper or clean, lint-free cloth. Forced air circulation in excess of normal ventilation in the inspection area shall not be used. The time for surface drying after removal of excess penetrant and prior to application of the developer shall be limited to a maximum of ten minutes.

3.6.3.2 Water Removable Penetrants (294564-2, -3, -4, -5, and -6): The drying of test surfaces shall be accomplished by using circulating air, blotting with paper towels or clean, lint-free cloth or by normal evaporation. It is important that during the drying operation no contaminating material be introduced onto the surface which may cause misinterpretation during the inspection operation.

3.7 PROCEDURE ON DEVELOPERS

3.7.1 Dry Developer (294564-4, -5, and -6): Dry developing powder shall be applied only on a dry surface so that matting will be prevented. Immediately after drying of the test surface, the powder shall be thinly but uniformly applied to provide a dusty appearance. The test surfaces shall not be evaluated sooner than 15 minutes after application of the developer.

3.7.2 Wet Developer (294564-3 and -4): This kind of developer shall be uniformly applied to surfaces by dipping, spraying or brushing after removal of all excess penetrant. When using liquid type developers, it is necessary that they be continually agitated in order to prevent settling of solid particles. Concentrations of wet developer in cavities on the inspection surface shall not be permitted, since these pools will dry to an excessively heavy coating, resulting in the masking of indications. The test surfaces shall not be evaluated sooner than 15 minutes after application of the developer.

3.7.3 Nonaqueous Wet Developer (294564-1, -2, -5, and -6): A nonaqueous wet developer recommended by the penetrant manufacturer shall be used. Immediately prior to application, the developing liquid shall be kept agitated in order to prevent settling of solid particles. The developer shall be uniformly applied in a thin coating to the test surfaces by spraying. If the geometry of the item being inspected precludes the use of a spray, a brush or similar applicator shall be used provided it results in a uniform, thin coating of developer. Pools of wet developer in cavities on the inspection surface shall not be permitted since these pools will dry to an excessively heavy coating, resulting in the masking of indications. The test surfaces shall not be evaluated sooner than 15 minutes after application of the developer.

3.8 FINAL CLEANING: The penetrant materials shall be removed as soon as possible after inspection by means of water or solvents in accordance with applicable specifications.

4. QUALITY ASSURANCE

4.1 COMPLIANCE: No change shall be made from these procedures without first obtaining the approval of the purchaser.

4.2 ACCEPTANCE CRITERIA: The criteria for acceptance standards in terms of size and distribution of indications are presented in Tables I and II. Table I shown class numbers for coding various combinations of size of indications and the number of indications of each size. Table II shows code letters which can be used to denote the distribution of indications per total area, per square inch, or along a linear dimension. Some examples of specified classes and the interpretations therof follow:

Class 0 - Surface or edge referenced shall be completely free of penetrant indications.

Class 00 - Surface or edge may have micro-porosity only.

Class 1-1a - Surface or edge referenced may have no more than two indications of 1/16-inch size per square inch and their centers shall be at least 3/8-inch apart.

Class 2-4C - Surface or edge referenced may have no more than two indications of 1/16-inch size per square inch and their centers shall be at least 3/8-inch apart.

Class 3-8K - Surface or edge referenced may have no more than three linearly-oriented indications of 1/8-inch size and the center of any two indications shall be at least 1/4-inch apart.

4.3 REJECTION STANDARDS

4.3.1 Parts showing indications in excess of those permitted by the class number and letter specified according to Section 4.2 on the applicable drawing or other purchasing document shall be subject to rejection.

4.3.2 Weldments and other parts with a relatively rough surface may reveal nonrelevant indications and shall be subject to the following interpretation. All indications in weld craters shall be considered relevant and shall be evaluated in accordance with applicable acceptance standards. If other indications are believed to be nonrelevant at least 10 percent of each type of indication shall be explored by removing the surface roughness or other conditions believed to have caused the type of indication to determine if defects are present. The absence of indications upon reinspection by liquid penetrant inspection after removal of the surface roughness shall be considered to prove that the indications were nonrelevant with respect to actual defects. If reinspection reveals any indications, these indications and all of the original indications shall be considered relevant and shall be evaluated in accordance with the acceptance standards

4.4 RECORDS AND REPORTS

4.4.1 Records: The type of penetrant used, and times for penetration and developing shall be recorded. For each part inspected, its identification and the size, shape, type, and number of defects found and their locations shall be recorded.

4.4.2 Reports: Five copies of the information recorded in compliance with Section 4.4.1 shall be submitted to the purchaser according to instructions on the purchase order.

TABLE I

CLASS NUMBERS FOR THE NUMBER AND SIZE OF INDICATIONS

Class No.	Indications: Number	Indications: Maximum Size, in.
0	No indications	
00	Microporosity condition (all indications under 1/64 in.)	
1-1	1	1/64
2-1	2	1/64
3-1	3	1/64
4-1	4	1/64
5-1	5	1/64
1-2	1	1/32
2-2	2	1/32
3-2	3	1/32
4-2	4	1/32
5-2	5	1/32
1-3	1	3/64
2-3	2	3/64
3-3	3	3/64
4-3	4	3/64
5-3	5	3/64
1-4	1	1/16
2-4	2	1/16
3-4	3	1/16
4-4	4	1/16
5-4	5	1/16
1-5	1	5/64
2-5	2	5/64
3-5	3	5/64
4-5	4	5/64
5-5	5	5/64
1-6	1	3/32
2-6	2	3/32
3-6	3	3/32
4-6	4	3/32
5-6	5	3/32

TABLE I (continued)

CLASS NUMBERS FOR THE NUMBER AND SIZE OF INDICATIONS

Class No.	Indications Number	Maximum Size, in.
1-8	1	1/8
2-8	2	1/8
3-8	3	1/8
4-8	4	1/8
5-8	5	1/8
1-12	1	3/16
2-12	2	3/16
3-12	3	3/16
4-12	4	3/16
1-16	1	1/4
2-16	2	1/4
3-16	3	1/4
4-16	4	1/4

TABLE II

CODE LETTERS FOR DISTRIBUTION OF INDICATIONS

Class Suffix Letter	Basis of Limits of Indications	Minimum Distance Between Centers, Inches
A	Total area or edge	-----
B	Per square inch	1/4
C	Per square inch	3/8
D	Per square inch	1/2
E	Per square inch	1
F	Per square inch	2
G	Per square inch	3
H	Per square inch	4
J	Per square inch	6
K	Per linear dimension	1/4
L	Per linear dimension	3/8
M	Per linear dimension	1/2
N	Per linear dimension	1
P	Per linear dimension	2
Q	Per linear dimension	3
R	Per linear dimension	4
S	Per linear dimension	6

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PROCESS SPECIFICATION 294502 Revision No. 1 October 13, 1967
(Not for Publication)

HELIUM LEAK TEST PROCESS PROCEDURES

1. PURPOSE

This procedure describes the test methods to be followed in determining the soundness of hermetically sealed vessel assemblies. Its application in no way relieves the supplier of the responsibility of performing any other nondestructive tests (including dye penetrant, ultrasonic, radiography, eddy current, etc.) contractually specified by the purchaser to ascertain the integrity of any component.

2. SCOPE

Two methods of testing are permitted - One involves subjecting (sealed) components to vacuum and, immediately thereafter, to a high pressure of helium in a pressure chamber; then employing a leak detector to detect the existence of any leaks through exceedingly small openings in the envelope or barrier separating two regions of different pressures. When permitted by the applicable drawing, components may be tested with a helium atmosphere while a leak detector is in communication with its inside space (See Section 6).

3. GENERAL REQUIREMENTS

3.1 Scheduling:

3.1.1 Leak testing shall be performed during pre-determined stages of fabrication and shall be preceded by stress relieving of the subassembly when completed vessels are stress relieved before final leak testing.

3.2 Precautions:

3.2.1 The vessel under test shall be absolutely clean and free from water vapor, oil, grease, and other contaminants which might affect leak test data.

3.2.2 The helium employed for testing shall be pure water pumped dry gas having a dew-point of 40°F or lower.

3.2.3 All unused vessel openings shall be sealed leaktight. All sealing material must be readily and completely removable after completion of the test.

4. INSTRUMENTATION

4.1 The leak detector used shall have a sensitivity of at least $1x10^{-8}$ standard cc He/sec., as determined with a standard leak, when operated at maximum throttle opening.

4.2 Operation of the leak detector shall be strictly in accordance with the manufacturer's instructions. At no time shall the leak detector pumps be used to evacuate external manifolds or vacuum chambers.

4.3 The vacuum system shall be calibrated daily for helium sensitivity. In calibrating the system the external vacuum pumps shall be blanked off and a standard leak placed at the furthest point from the leak detector. The standard leak used to calibrate the system shall be at least $1x10^{-6}$ standard cc He/sec. and shall be handled with extreme care to prevent plugging or breakage. Calibration shall be concluded as soon as the system sensitivity reaches a minimum of $1x10^{-8}$ standard cc He/sec.

4.4 The leak tester and vacuum system shall be tested for helium background daily. System background with the external pumps blanked off shall be no more than 5% of full scale (when the unit is set at maximum sensitivity) after five minutes of continuous testing. If units with an adjustable zero are used, total system background shall be reduced to below that specified above.

4.5 The components tested shall be free of dirt, grease, burrs, etc. which would either tend to clog defects or damage the pressure and vacuum fittings.

4.6 Leak testing shall be performed in well ventilated areas to minimize the possibility of detecting helium-contaminated air.

4.7 The vacuum system shall be constructed from corrosion resistant materials and kept scrupulously clean at all times. All flexible connections shall be made of neoprene.

5. TEST PROCEDURE

5.1 Pressurizing Operation:

5.1.1 Place component assemblies in pressure manifold and seal. Make certain that all assemblies are clean and free of any porous materials which may absorb helium.

5.1.2 Evacuate the pressure manifold for 20 minutes minimum after attaining a vacuum pressure of 10 to 15 microns of Hg.

5.1.3 Close pressure chamber vacuum valve.

5.1.4 Open helium inlet valve allowing chamber pressure to reach 100 psi, minimum.

5.1.5 Maintain helium pressure at 100 psi. for 20 minutes minimum.

5.1.6 Close helium inlet valve, release pressure and remove the component assemblies from the pressure chamber.

5.1.7 The pressure chamber may be reloaded and operations 5.1.1 through 5.1.6 repeated under continuous operating conditions.

5.1.8 Allow component assemblies to stand in air for a minimum of 10 minutes and maximum of 24 hours before helium leak testing, to allow any residual helium which may be absorbed on the outside surfaces of the component assemblies to diffuse into the air.

5.2 Calibration of Equipment:

5.2.1 General

5.2.1.1 Calibration will be made after each period of shutdown greater than 1/2 hour and a minimum of three times per shift at the beginning of the shift, after the lunch period and at the end of the shift on continuous production. Results of each calibration will be recorded on the production record form.

5.2.1.2 The recorded information will be as follows:

a. Location of calibrated leak tube.

b. Date and time of day.

c. Component assembly batch tested before and after calibration.

d. The magnitude of the output meter deflection at an amplification of 10X, 5X, and 1X.

5.2.1.3 During calibration the calibrated leak tube will be located at the area in which the component assemblies will be tested, or at a point in the chamber furthest from the leak detector.

5.2.1.4 All calibration tests will be conducted with the throttle valve wide open and a manifold pressure of 0.2 microns of Hg or less.

5.2.1.5 To insure that deflection recorded during calibration is not caused by residual helium contained in the system, no deflection of the meter should be evident when the leak source is removed or switched off.

5.2.1.6 The sensitivity of the leak detector should be the same or more sensitive than the limits indicated under paragraph 4.1.

5.2.1.7 If it is found that the leak detector does not meet the calibration standard, all components tested between calibration tests shall be retested.

5.2.2 Procedure for Establishing Acceptance Number

5.2.2.1 Use a known standard glass leak tube; for example, 7.4×10^{-7} cc/sec. This is to be connected to the component testing chamber.

5.2.2.2 When pressure in the empty chamber is less than .2 microns as indicated on the multi-purpose meter on the leak detector, turn on the standard leak.

5.2.2.3 Pump on the standard leak until a stable reading on the output meter is reached. This is indicated by a meter change of less than five per cent in two minutes. All valves between the standard leak and the detector should be wide open.

5.2.2.4 Record the meter reading and scale (Reading "A").

5.2.2.5 Turn off leak, stabilize reading as in paragraph 5.2.2.3 and record meter reading and scale (Reading "B").

5.2.2.6 Then:

$$\frac{\text{standard leak rate}}{\text{"A"} - \text{"B"}} = \text{sensitivity} *$$

$$\text{Example: } \frac{7.4\text{x}10^{-7}}{(21\text{x}10) - (10\text{x}1)} = \frac{7.4\text{x}\ 10^{-7}}{200} = 3.7\text{x}10^{-9} \text{ cc/sec.}$$

5.2.2.7 Calculate the acceptance number as follows:

$$\frac{\text{maximum component leak rate}}{\text{sensitivity}} = \text{acceptance number}$$

$$\text{Example: } \frac{5\text{x}10^{-8}}{3.7\text{x}10^{-9}} = 13.5$$

5.3 Leak Testing

5.3.1 Fill chamber with as many component assemblies as convenient and pump down to low pressure with the roughing pump.

* If unspecified, a figure of $5\text{x}10^{-8}$ cc/sec. shall be considered the minimum acceptable.

5.3.2 Using the same procedure as when determining sensitivity, open valves to the leak detector.

5.3.3 When pressure indicated on multi-purpose meter is below .2 microns, turn on filament.

5.3.4 After allowing meter to stabilize (no more than 5% increase in 2 minutes),record the reading on the output meter if it goes below the previously determined acceptance number, accept all components in the chamber. Record component lot numbers and the reading on the output meter.

5.3.5 If the audible signal is set at less than the acceptance number, it is acceptable to record the reading as less than the audible signal.

5.3.6 If a leak is indicated by a reading greater than the acceptance number, separate the components into smaller batches until the leaking tube is identified.

5.3.7 Record all data that would be required to duplicate the test.

6. ALTERNATE TEST PROCEDURE

6.1 Section 5 requirements may be waived and components shall be leak tested in accordance with Section 6.3.2 Individual Hood Method and Section 6.4 Probe Method of MIL-STD-271D.

6.2 A leak shall be defined as an increase of greater than 5% of full scale reading of the leak rate meter above background (when the leak detector is set at maximum sensitivity) after five minutes of continuous testing.

APPENDIX G

RAW MATERIAL INSPECTION

All T-111 Tubing was supplied to NASA Specification C-393643 dated 1/27/69 and all T-111 rod was supplied to NASA Specification C-393644 dated 1/14/69. Thermocouples, except for 1/8 dia. WANL fabricated, were procured to NASA Specification C-405955. All 304 stainless steel tubing was purchased to specification ASTM-A-213 and all 304 stainless round stock was purchased to specification ASTM-A-276.

Listed in Table G-1 is a cross reference of each part, the raw material from which it was made, inspection of the raw material, heat number, fabrication process, finished part inspection and capsule or fuel pin in which part was used. Table G-2 is a summary of certified test reports for tantalum and T-111 alloy raw material and Table G-3 is for the 304 stainless steel.

The helium gas used was "Airco Ultra High Purity Grade 5 Helium" purchased from the Air Reduction Company, Inc., Riverton, New Jersey. Impurity level was guaranteed not to exceed the following:

	ppm
H_2	- 1.0
H_2O	- 1.5
O_2	- 1.0
N_2	- 5.0
Ne	- 2.0
$Co + Co_2$	- 0.5
Total Hydrocarbons	- 0.5

Lot No. 1 was used on all Phase I and II capsules and fuel pins and had the following impurity levels as analyzed by Westinghouse:

	ppm
H_2	- 0.56
H_2O	- < 2.0 (monitored at < .5)
O_2	- 0.58
N_2	- 3.18
Ne	- 0.22
Ar	- 0.33
CO_2	- 0.28

Lot No. 2 was used on all Phase III fuel pins and had the following impurity levels as analyzed by Westinghouse:

	ppm
H_2	- 0.04
H_2O	- < 2.0 (monitored at < 0.5)
O_2	- 0.33
N_2	- 2.22
Ne	- 1.06
Ar	- 0.01
CO_2	- 0.06
CH_4	- 0.01

Drawing No.	Part No. and Name	Description of Raw Material	Raw Material Inspection	Heat No.	Fabrication Process	Finished Part Inspection	Capsule or Fuel Pin No.
CD-352462-1	No. 1 Capsule Top End Cap	304 St. Stl. Rod 5/8" Dia.	Visual, dimensional, dye penetrant, hardness, metallographic	54755	Machining	Visual, dimensional	All Phase I & II D/2 size capsules except as listed below
"	No. 1 Capsule Top End Cap	304 St. Stl. Rod 5/8" Dia.	Visual, dimensional, dye penetrant, hardness, metallographic	G-5657	Machining	Visual, dimensional	901-503G, H, & I 901-501F & H
"	No. 2 Capsule Bottom End Cap	304 St. Stl. Rod 5/8" Dia.	Visual, dimensional, dye penetrant, hardness, metallographic	54755	Machining	Visual, dimensional	All Phase I & II D/2 size capsules except as listed below
"	No. 2 Capsule Bottom End Cap	304 St. Stl. Rod 5/8" Dia.	Visual, dimensional, dye penetrant, hardness, metallographic	G-5657	Machining	Visual, dimensional	901-501 F & H 901-503 G, H, & I
"	No. 3 Fuel Pin End Caps	T-111 Rod 3/8" Dia.	Visual, dimensional, dye penetrant, hardness, metallographic, chemistry	650062	Machining	Visual, dimensional, dye penetrant, weight	All Phase I & II D/2 size fuel pins
"	No. 4 Fuel Pin Tubes	T-111 Tubing .375 OD x .033 Wall	Visual, dimensional, ultrasonically, dye penetrant, metallographic, hardness, chemistry	8177	Machining	Visual, dimensional (recorded) weight	All Phase I & II D/2 size fuel pins
"	No. 5 Capsule Tube	304 St. Stl. Tubing 5/8" OD x .120 Wall	Visual, dimensional, ultrasonically, dye penetrant, metallographic, hardness	03775	Machining	Visual, dimensional (recorded)	All Phase I & II D/2 size capsules except 901-503 G & I which were made from Heat G-5657
"	No. 6 Fuel Pin Spacer	T-111 Rod 1/2" Dia.	Visual, dimensional, dye penetrant, metallographic, hardness	650062	Machining	Visual, dimensional	All Phase I & II D/2 size capsules
"	Nos. 7&8 Thermocouple Well - St. Stl. Section	304 St. Stl. Tubing 1/8 OD x .035 Wall	Visual, dimensional, dye penetrant	6-5927	Machining	Visual, dimensional	All Phase I & II D/2 size capsules except as listed below
"	Nos. 7&8 Thermocouple Well - St. Stl. Section	304 St. Stl. Tubing 1/8 OD x .035 Wall	Visual, dimensional, dye penetrant	429149	Machining	Visual, dimensional	901-501 C, D, E, & F 901-503 D, E, F, G, H, & I
"	Nos. 7&8 Thermocouple Well - Ta Tube	Tantalum Tubing .062 OD x .005-.006 Wall	Visual, dimensional, dye penetrant, metallographic, hardness	Lot 802X3	Machining	Visual, dimensional	All Phase I & II D/2 size capsules
"	Nos. 7&8 Thermocouple Well - Ta Plug	Tantalum Rod 1/16 Dia.	Visual, dimensional, dye penetrant		Machining	Visual, dimensional	All Phase I & II D/2 size capsules
CD-352462-1	No. 9 Thermocouple Protective Tube				Formed by chemical vapor deposition of tungsten on moly mandrel then etching mandrel away	Visual, dimensional, dye penetrant, x-ray, weight	All Phase I & II D/2 size fuel pins
"	No. 10 Tungsten Liner	Supplied by NASA			Cut to length & etch mandrel away	Visual, dimensional, dye penetrant, x-ray, weight	All Phase I & II D/2 size fuel pins

Table G-1. Raw Material Cross Reference

Drawing No.	Part No. and Name	Description of Raw Material	Raw Material Inspection	Heat No.	Fabrication Process	Finished Part Inspection	Capsule or Fuel Pin No.
CD-352462-1	No. 11 Washer, Flat Tungsten	Supplied by NASA				Visual, dimensional, weight	All Phase I & II D/2 size fuel pins
"	No. 12 Spherical Spacer	Supplied by NASA		70616	Formed	Visual, dimensional, weight	All Phase I & II D/2 size fuel pins
"	No. 13 Thermocouple Assembly	Stainless steel sheathed lead Supplied by NASA			Hot junction & cold end prepared in accordance with drawing & assy. procedure	Visual, dimensional, electrical	All Phase I & II D/2 size fuel pins
"	No. 14 Fuel Pellets (UN)	Supplied by NASA			Isostatic hot pressing & machining	Visual, dimensional, spot checks	All Phase I & II D/2 size fuel pins
"	No. 15 Spring, Tungsten	Supplied by NASA			Formed	Visual, dimensional, weight	All Phase I & II D/2 size fuel pins
"	No. 16 Flux Monitoring Wire	Supplied by NASA			Formed	Visual, dimensional, weight	All Phase I & II D/2 size fuel pins
CD-352463-1	No. 1 Capsule Top End Cap	304 St. Stl. Rod 1.0" Dia.	Visual, dimensional, dye penetrant, metallographic, hardness	55507	Machining	Visual, dimensional	All Phase I & II D size capsules
"	No. 2 Capsule Bottom End Cap	304 St. Stl. Rod 1.0" Dia.	Visual, dimensional, dye penetrant, metallographic, hardness	55507	Machining	Visual, dimensional	All Phase I & II D size capsules
"	No. 3 Fuel Pin End Cap	T-111 Rod .750" Dia.	Visual, dimensional, dye penetrant, hardness, metallographic, chemistry	650061	Machining	Visual, dimensional, dye penetrant, weight	All Phase I & II D size capsules
"	No. 4 Fuel Pin Tube	T-111 Tubing .744 OD x .067 Wall	Visual, dimensional, ultrasonically, dye penetrant, metallographic, hardness, chemistry	8173	Machining	Visual, dimensional, (recorded) weight	D-2
"	No. 4 Fuel Pin Tube	T-111 Tubing .755 OD x .067 Wall	Visual, dimensional, ultrasonically, dye penetrant, metallographic, hardness, chemistry	8480	Machining	Visual, dimensional, (recorded) weight	All Phase I & II D size fuel pins except D-2
"	No. 5 Capsule Tube	304 St. Stl. Tube 1.0" OD x .120" Wall	Visual, dimensional, ultrasonically, dye penetrant, hardness, metallographic	1-2486	Machining	Visual, dimensional (recorded)	All Phase I & II D size capsules and fuel pins
"	No. 6 Fuel Pin Spacer	T-111 Rod 1.0" Dia.	Visual, dimensional, dye penetrant, metallographic, hardness	650061	Machining	Visual, dimensional, weight	All Phase I & II D size capsules and fuel pins
"	Nos.7&8 Thermocouple Well - St. Stl. Section	304 St. Stl. Tubing 1/4 OD x .083 Wall	Visual, dimensional, dye penetrant	M-2719	Machining	Visual, dimensional	All Phase I & II D size capsules and fuel pins
"	Nos.7&8 Thermocouple Well - Ta Tube	Tantalum Tubing .094 OD x .007 Wall	Visual, dimensional, dye penetrant, metallographic, hardness		Machining	Visual, dimensional	All Phase I & II D size capsules and fuel pins
"	Nos.7&8 Thermocouple Well - Ta Plug	Tantalum Rod 1/8 Dia.	Visual, dimensional, dye penetrant		Machining	Visual, dimensional	All Phase I & II D size capsules and fuel pins
"	No. 9 Thermocouple Protective Tube				Formed by chemical vapor deposition of tungsten on moly mandrel then etching mandrel away	Visual, dimensional, dye penetrant, x-ray	All Phase I & II D size capsules and fuel pins

Table G-1. Raw Material Cross Reference (continued)

Drawing No.	Part No. and Name	Description of Raw Material	Raw Material Inspection	Heat No.	Fabrication Process	Finished Part Inspection	Capsule or Fuel Pin No.
CD-352463-1	No. 10 Tungsten Liner	Supplied by NASA			Cut to length & etch mandrel away	Visual, dimensional, dye penetrant, x-ray, weight	All Phase I & II D size capsules and fuel pins
"	No. 11 Washer, Flat Tungsten	Supplied by NASA			EDM	Visual, dimensional, weight	All Phase I & II D size capsules and fuel pins
"	No. 12 Spherical Spacer	Supplied by NASA		65076	Formed	Visual, dimensional, weight	All Phase I & II D size capsules and fuel pins
"	No. 13 Thermocouple Assembly	Stainless steel sheathed leads Supplied by NASA			Hot junction & cold end prepared in accordance with drawing & assy. procedure	Visual, dimensional, electrical	All Phase I & II D size capsules and fuel pins
"	No. 14 Fuel Pellets	Supplied by NASA			Isostatic hot pressing & machining	Visual, dimensional, spot check	All Phase I & II D size capsules and fuel pins
"	No. 15 Spring, Tungsten	Supplied by NASA			Formed	Visual, dimensional, weight	All Phase I & II D size fuel pins
"	No. 16 Flux Monitoring Wire	Supplied by NASA			Formed	Visual, dimensional, weight	All Phase I & II D size fuel pins
"	No. 17 Thermocouple Assembly	Stainless steel sheathed leads Supplied by NASA			Hot junction & cold end prepared in accordance with drawing & assy. procedure	Visual, dimensional electrical	All Phase I & II D size fuel pins
CD-352465-1	No. 1 Fuel Pin Bottom End Cap	T-111 Rod 3/8 Dia.	Visual, dimensional, dye penetrant, hardness, metallographic, chemistry	650062	Machining	Visual, dimensional, dye penetrant, weight	All Phase III fuel pins
"	No. 2 Fuel Pin Top End Cap	T-111 Rod 3/8 Dia.	Visual, dimensional, dye penetrant, hardness, metallographic, chemistry	650062	Machining	Visual, dimensional, dye penetrant, weight	All Phase III fuel pins
"	No. 3 Fuel Pin Tube	T-111 Tubing	Visual, dimensional, ultrasonically, dye penetrant, metallographic hardness, chemistry	8177	Machining	Visual, dimensional, (recorded) dye penetrant, weight	All Phase III fuel pins
"	No. 4 Thermocouple Protective Tube				Formed by chemical vapor deposition of tungsten on moly mandrel then etching mandrel away	Visual, dimensional, dye penetrant, x-ray, weight	All Phase III fuel pins
"	No. 5 Loose Liner	Supplied by NASA			Cut to length & etch mandrel away	Visual, dimensional, dye penetrant, x-ray, weight	All Phase III fuel pins
"	No. 6 (UN) Fuel Pellets	Supplied by NASA				Visual, dimensional, spot check	All Phase III fuel pins
"	No. 7 Washer, Flat Tungsten	Supplied by NASA				Visual, dimensional, weight	All Phase III fuel pins

Table G-1. Raw Material Cross Reference (continued)

Drawing No.	Part No. and Name	Description of Raw Material	Raw Material Inspection	Heat No.	Fabrication Process	Finished Part Inspection	Capsule or Fuel Pin No.
CD-352465-1	No. 8 Spherical Spacer	Supplied by NASA		65076	Formed	Visual, dimensional, weight	All Phase III fuel pins
"	No. 9 Flux Monitoring Wire	Supplied by NASA			Formed	Visual, dimensional, weight	All Phase III fuel pins

Table G-1. Raw Material Cross Reference (continued)

Heat or Lot No.	C	N_2	O_2	H_2	Cb	Ti	Fe	Mn	Si	Sn	Ni	Cr	Ca	Na	Al	Mo	Cu	Zr	Co	Mg	V	W	Hf	Ta
	Chemical Composition																							
	P. P. M.																					Percent		
802X3	25	<10	<50	≤5	60	<5	<5	<5	<5	<5	<5	<5	5	ND	<5	15	<5	<5	<5	<5	--	<25 ppm	--	
8177	30	29	14	1.3	250	---	1	--	---	--	<1	<1	-	--	--	20	---	500	10	--	4	7.55	2.46	
650062	<40	10	40	2.1	400	<20	<20	--	<20	--	<10	<10	-	--	--	20	<20	400	<5	--	<10	8.2	2.0	BAL
8173	21	29	16	1.6	900	---	1	--	---	--	---	<1	-	--	--	20	---	.400	10	--	2	7.40	2.46	
8480	49	41	<5	5	150	---	10	--	---	--	---	<1	-	--	--	30	---	810	<5	--	2	7.69	1.96	
650061	<40	20	60	2.3	315	<20	<20	--	<10	--	<10	<10	-	--	--	15	<20	<1000	<5	--	<10	8.1	2.1	

Heat No.	Yield (PSI)	Ultimate (PSI)	Elong. a/o, 2"	Hardness	Avg. Grain Size
Mechanical Properties					
8177	79,800	89,900	37.0	B 97.6/98.4	No. 6
650062	-----	-----	---	BHN 217	No. 6.5
8173	80,000	93,300	52.0	B 86.8/623	No. 5
8480	86,000	95,800	34.0	B 96.5/97	No. 5
650061	-----	-----	---	BHN 220	No. 8

Table G-2. Tantalum and T-111 Raw Material Certified Test Report Summary

Chemical Composition Percent														Mechanical Properties				
Heat No.	C	Mn	P	S	Si	Cr	Ni	Fe	Cu	Al	Mn	Mo	Co	Ten. Str. PSI	Yield PSI	Elong. a/o-2"	Red. Area a/o	Hardness
54755	.060	.55	.020	.025	.44	18.68	8.80		.21	--	--	.30	.12	101,500	80,000	43.8	73.0	RB/98
G-5657	.072	1.53	.023	.022	.62	18.70	8.44		.25	--	--	.42	.15	89,800	57,000	55.0	76.0	BHN/212
03775	.070	1.71	.014	.025	.53	18.40	9.87		--	--	--	--	--	86,000	47,200	60.9	---	RB/76
6-5927	.05	1.32	.025	.022	.35	18.70	9.30	BAL	--	--	--	--	--	93,220	40,254	58	---	OK
429149	.043	.45	.017	.007	.45	18.2	9.0		.05	--	--	.50	.023	94,000	39,400	60	---	RB 66/70
55507	.052	.47	.034	.018	.47	18.04	8.73		.30	--	--	.36	.14	92,800	62,000	51.1	72.3	BHN/197
1-2486	.05	1.27	.022	.017	.40	18.30	9.90		--	--	--	--	--	88,233	46,449	61	---	OK
M-2719	.061	1.66	.023	.016	.47	19.9	9.97		.09	--	--	.32	.03	91,605	41,635	57	---	---

Table G-3. 304 Stainless Steel Raw Material Certified Test Report Summary

APPENDIX H

CLEANING PROCEDURES

A. Cleaning Procedures for T-111, Ta and Tungsten

(Note: To assure optimum cleanliness, perform cleaning operation as near to time of use as practical.)

1. Degrease parts by M-6 (oxylene) solvent rinse or ultrasonic cleaning.
2. Pickle with nitric-hydrofluoric-sulfuric acid solution nominally 20-15-10% balance water by volume. Time one to two minutes.
3. Rinse as follows)This is the most important step since pickling residues can cause surface contamination or degas severely on heating).
   a. Fast transfer from pickle bath to rinse without any surface drying of pickle solution.
   b. 30 seconds boiling distilled water.
   c. 1 minute flowing cold water.
   d. 5 minutes boiling distilled water (not the same water as in "b" above).
   e. Fast rinse in ethyl alcohol.
   f. Hot air flash dry.
4. Store in clean glass containers and/or in clean dry kim wipes. Polyethelene bags or other plastic containers not acceptable.
5. Handle only with clean tools or lint free gloves on top of pylox or quixams gloves.
6. Degas for 10 minutes at 2400°F wrapped in tantalum foil in vacuum 5×10^{-5} torr or better. Furnace cool to room temperature before removing. (Note: Final fuel pin cleaning before capsule assembly degas at 2000°F instead of 2400)

B. Stainless Steel Cleaning

(Note: To assure optimum cleanliness, perform cleaning operation as near to time as use as practical.)

1. Scrub with "Comet" cleanser.
2. Rinse in flowing hot tap water.
3. Rinse in boiling distilled water.
4. Wash with ethyl alcohol.
5. Air dry (Hot air flash drying with heat gun acceptable).
6. Handle only with clean tools or lint free gloves over pylox or quixams gloves.
7. Store in clean glass containers and/or in clean dry kim wipes. Polyethelene bags or other plastic containers not acceptable.

C. Tools and Fixtures for Handling Refractory Metals

1. All tools and fixtures that contact refractory metal parts for welding or final assembly must be constructed of refractory metal or coated with refractory metal.
2. Tools and equipment are to be cleaned prior to use by the methods described below.

D. Small Tools and Equipment and Cleaning

1. Degrease all small tools and equipment by ultrasonic cleaning or M-6 (oxylene) rinse.
2. Rinse with ethyl alcohol.
3. Air dry (Hot air flash drying with heat gun acceptable).

E. Large Tools, Equipment and Containers

1. Degrease by wiping with rag or kim wipe saturated with M-6 or other suitable solvent.
2. Wipe dry with clean rag or kim wipe.
3. Wipe with rag or kim wipe dampened with ethyl alcohol.
4. Air dry.

APPENDIX I

WELDING AND BRAZING PROCEDURES

Fusion Welding

The principal document applied in the control of all fusion welding, either electron beam or tungsten arc, is WANL process specification PS 294614-1 (attached). This specification defines general weld quality requirements as revealed by visual, dye penetrant and radiographic (where applicable) inspection.

Helium leak testing is also performed at various assembly stages as noted in Assembly Procedures.

The welding specification defines the requirements for procedure qualification prior to production welding. Two sample parts must be produced with the final parameters to demonstrate capability. A "Welding Procedure Sheet" is prepared for each weld joint, defining the techniques employed. The procedures required for this program are attached. Also attached is a cross reference of Procedures to applicable fuel pins or capsules, Table 1-1.

TABLE I-1

CROSS REFERENCE OF PROCEDURE TO APPLICABLE FUEL PINS OR CAPSULES

Welding or Brazing Procedure No.	Reference Weld Schematic for Capsule Assemblies Figure 6	Fuel Pin Or Capsule Constructed By This Procedure
70336-1	6	All D/2 X Fuel Pins
70336-2	4	All D/2 Capsules Except Those Listed in 70336-2A Below
70336-2A	4	901-503D, E, F, G, H & I 901-501C, D, E & F
70336-3	3	All D/2 Capsules
70336-4	8	All D/2 Capsules
70336-5	6	All D/2 Y Fuel Pins
70336-6	2	All D/2 Capsules Except as Listed in 70336-20 Below
70336-7	4	All "D" Capsules Except Those Listed in 70336-7A Below
70336-7A	4	901-504C, E & D 901-502B & C
70336-8	3	All "D" Capsules
70336-9	8	All "D" Capsules
70336-10	6	D-2 Fuel Pin
70336-10A	6	All D-X Fuel Pins Except D-2
70336-11	6	504A & B
70336-11A	6	All D-Y Fuel Pins Except 504A & B
70336-12	2	All "D" Capsules Top End Cap Except as Listed in 70336-19 Below
70336-13	9	All D/2 Fuel Pins
70336-14	9	All "D" Fuel Pins

TABLE I-1 (Cont.)

Welding or Brazing Procedure No.	Reference Weld Schematic for Capsule Assemblies Figure 6	Fuel Pin Or Capsule Constructed By This Procedure
70336-15	7	All D & D/2 Capsules
70336-16	2	All "D" Capsules Bottom End Cap Except as Listed in 70336-19 Below
70336-17	5	All D/2 Capsules Except: 901-503B-1, 901-503C-1, 901-503A & C, 901-D7
70336-18	5	All "D" Capsules Except: 901-D2, 901-504B, 901-504B-1
70336-19	2	901-502B & C 901-504D (Top & Bottom End Caps)
70336-20	2	901-501C, D, E & F 901-503F & H
70336-21	1	901-502B & C, 901-504D
70336-22	1	901-501C, D, E & F, 901-503F & H
70336-23	10 & 11	901-502B & C, 901-504D
70336-24	4	Fuel Pins 505A, B, E & F, 509A, B, C, & D, 507A, B, C & D
70336-B1	1	All Capsules Except Those Listed in Procedures 70336-21 & 70336-22 Above

INFORMATION CATEGORY

UNCLASSIFIED

9/10/64

Authorized Classifier Date

Westinghouse Electric Corporation

Astronuclear Laboratory
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Pittsburgh, Pa. 15236
(Fed. Ident. Code No. 14683)

*PROCESS SPECIFICATION 294614, Revision No. 1
(Not for Publication)

November 21, 1968

WELDING, FUSION - AUSTENITIC STAINLESS STEELS FOR POWER GENERATING SYSTEMS

1. SCOPE

This specification covers requirements for fusion welding of austenitic stainless steels by the inert-gas tungsten arc, inert-gas metal arc, or electron beam process, intended for liquid metal or radioisotope heat source power generating systems, designated as follows:

Designation	Description
294614-1	Fusion welding of AISI 300 series stainless steels for systems requiring sound welds with no surface defects as indicated by liquid penetrant inspection.
294614-2	Fusion welding of AISI 300 series stainless steels for systems requiring sound welds with less restrictive surface quality requirements than 294614-1.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect, shall form a part of this specification to the extent specified herein.

MIL-T-5021 MIL-E-19933 MIL-STD-271 PS 294564 PDS 52118AE

2.2 Copies of MIL Specifications and Standards required by contractors in connection with specific procurement functions should be obtained as indicated in the Department of Defense Index of Specifications and Standards.

3. REQUIREMENTS

3.1 SAFETY: Some of the materials and/or operations required by this specification may be hazardous. The vendor is requested to consult a qualified Safety or Industrial Hygiene Engineer for necessary precautions. If processed by a Westinghouse plant, the instructions in Safe Practice Data Sheet, for example, Sheet W-1, shall be consulted to obtain information regarding the nature and properties of any material or processing requirement to avoid accident to employees or damage to equipment.

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GDR/mms

3.2 MATERIAL AND EQUIPMENT

3.2.1 Maintain all equipment including accessories, holders, leads, ground connections and any other equipment necessary to fulfill requirements of this specification at a level such that welds meeting the quality standards of this specification may be consistently produced. Maintenance within minimum accepted safety requirements is also required.

3.2.2 The welding area shall be protected from air movement due to fans, welding generators, open windows, exhaust hoods, etc.

3.2.3 The materials shall be as specified on the applicable drawing.

3.3 SURFACE PREPARATION: All foreign material shall be removed from both sides of the area that is to be welded or that will be heated by the welding.

3.3.1 All parts shall be free of grease and oil and other possible contaminates such as marking crayons, layout dyes, inks and similar materials prior to welding.

3.3.2 All oxides shall be removed from the immediate vicinity of the area to be welded. Extreme care shall be exercised in the cleaning procedures applied to each restrike area and to each completed weld prior to application of the next bead. All grit residue shall be removed with a clean, stainless steel wire brush prior to further welding. Pits or laps shall be blended mechanically before welding over them.

3.4 PROCESS

3.4.1 Manual or automatic inert-gas shielded tungsten arc or inert-gas metal arc processes, or the electron beam process shall be used.

3.4.2 Wherever feasible, grooved back-up bars or inert-gas backing shall be employed.

3.4.3 For tungsten arc welding, the electrode shall be the thoriated type and dressed to a point the diameter of which is one half that of the base.

3.4.4 Unless otherwise specified, the filler wire shall be as follows:

Base Material	Filler Wire
AISI 304	MIL-E-19933, Type 308
AISI 304L	MIL-E-19933, Type 308L
AISI 310	MIL-E-19933, Type 310
AISI 316	MIL-E-19933, Type 316
AISI 316L	MIL-E-19933, Type 316L
AISI 321	MIL-E-19933, Type 308L or 347
AISI 347 or 348	MIL-E-19933, Type 308L or 347

3.4.5 Shielding and backup gas shall be welding grade argon as specified by PDS 52118 AE.

3.4.6 Each weld pass shall be visually inspected and any porosity, surface cracks or oxide removed prior to additional welding (See Section 3.3).

3.5 PROCEDURE QUALIFICATION

3.5.1 The detailed welding procedure shall be qualified for production welding of parts covered by this specification by producing a minimum of two acceptable welds simulating actual production welding position and conditions. The qualification welds shall be made on parts which simulate the heat sink and joint configuration of the actual parts.

3.5.2 The qualification welds shall conform to the applicable quality requirements of Section 4.4.

3.5.3 At least one cross section through each of the qualification welds shall be polished and etched. These sections shall reveal no cracks, excessive oxide, lack of penetration or incomplete fusion.

3.5.4 The detailed welding procedure used in producing the qualification welds shall be documented and include all appropriate weld parameters, joint configuration, and all pertinent information of welding power source, torch, and accessory equipment and be submitted to the purchaser for approval prior to production welding. The results of the required quality control inspection shall also be included.

3.6 PERSONNEL QUALIFICATION:

3.6.1 (294614-1) Manual welding shall require qualification according to the detailed procedure defined in Section 3.5, and shall require qualification according to MIL-T-5021 for the applicable material.

3.6.2 (294614-2) For manual welding, the operator performing a procedure qualification as defined in Section 3.5 shall be considered qualified. Once the procedure has been approved, any operator certified to MIL-T-5021 for the applicable material may perform production welds using the approved procedure for a given joint configuration.

4. QUALITY ASSURANCE

4.1 SURVEILLANCE: Adherence to the provisions of this specification shall be under the surveillance of a Westinghouse Quality Control representative.

4.2 COMPLIANCE: No change shall be made from this specification, or an approved procedure, without first obtaining written approval of the purchaser.

4.3 PRODUCTION WELDING: Production welding shall be performed using only an approved procedure and a qualified operator for manual welding.

4.4 INSPECTION

4.4.1 Liquid Penetrant

4.4.1.1 (294614-1): Both sides of the root pass (if accessible) and the surface of the final weld pass, shall be penetrant inspected in accordance with 294564-1 and shall conform to class 0 acceptance standard.

4.4.1.2 (294614-2): Both sides of the root pass (if accessible) and the surface of the final weld pass shall be liquid penetrant inspected in accordance with 294564-1 and shall conform to the followin

4.4.1.2.1 No cracks or crack type indications shall be permitted.

4.4.1.2.2 The weld shall conform to 294564-1, class 3-2A requirements.

4.4.2 Visual: The weld surface shall be smooth, free of cracks, laps, and unfused areas. No undercut or depressions below the level of the base metal shall be permitted on the face or root of the weld. For butt welds a maximum of 0.050 inch root reinforcement and a minimum total weld thickness of 125% of the base metal thickness is required unless otherwise specified by the drawing. A visible smooth 100% penetration shall be required at the root of all welds exposed to liquid metals.

4.4.3 Radiography: When specified by an applicable drawing, radiographic inspection shall be conducted on all qualification and production welds. The inspection shall be in accordance with MIL-STD-271. Acceptance criteria are as follows:

4.4.3.1 (294614-1) Indications of defects or discontinuities on a radiograph shall be referred to the responsible engineer for his review and disposition.

4.4.3.2 (294614-2) The following shall be cause for rejection:

4.4.3.2.1 Cracks.

4.4.3.2.2 Lack of fusion or root penetration.

4.4.3.2.3 Porosity or inclusions with sharp tails.

4.4.3.2.4 Linear porosity or inclusions. Linear porosity is defined as the condition in which three (3) or more indications having a diameter 1/32 inch or over intersect a straight line parallel to the longitudinal axis of weld and their distance of closest approach is less than 1/8 inch.

4.4.3.2.5 The scattered porosity and inclusion standard shall be as follows:

Minimum Thickness of Materials Being Joined	Maximum Allowable Void Diameter	Minimum Allowable Spacing	Maximum Frequency (indications of any size per inch of weld)
0 - 1/4"	1/3 T or 3/64" (whichever is less)	3 times the diameter of the largest of any two adjacent defects.	4
1/4 - 3/8"	1/4 T	"	6

4.5 REPAIR

4.5.1 Weld defects in excess of the requirements of Section 4.4 shall be removed using a small carbide burr, grinding wheel, or file.

4.5.2 The weld shall be liquid penetrant inspected in accordance with 294564-1 to insure complete removal of the defect. If this inspection reveals the continued presence of the defect, Section 4.5.1 shall be repeated.

4.5.3 All penetrant and developer shall be removed prior to rewelding by wiping with a clean, lint-free cloth saturated with methanol or other equivalent solvent.

4.5.4 Where complete removal of surface defects can be accomplished by the removal of metal such that the weld still meets all size and quality requirements, no further repair work shall be required.

4.5.5 All weld repairs shall meet the quality requirements of Section 4.4 of this specification.

4.6 REPORTS: A report shall be prepared covering the welding of each assembly or subassembly and submitted to the responsible engineer. The minimum content shall be the date, equipment identification, details of welding procedure, identification of parts by name and number, operator qualification details and date qualified, and a statement that the welds conformed to the requirements of Section 4.4.

Procedure No.: 70336-1

Date: 10/8/69

WELDING PROCEDURE

Name of Part: Fuel Pin End Cap - Tube (D/2-X) Drawing No. NASA CD-352462-1

Welding Spec. No. ______

Material: T-111 Alloy Material Spec. No. ______

Description of Welds Covered by this Procedure: shoulder, Joint - .029" Min.
(type, size, location)
Penetration - .375" Dia. Tube - X Capsule

Welding Process: Electron Beam

Welding Machine: Sciaky - 30 KW Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. NONE Spec. ______

Shielding Gas ______ Backup Gas ______

Cleaning Prior to Welding: Pickle and Degas, handle with lint free gloves, contact only with refractory metal tools and fixtures

Detailed Procedure:

	Pass	Pass	Pass
Current	46 Milliamps		
Voltage	27.5 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	60 RPM (910 Pot Setting)		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

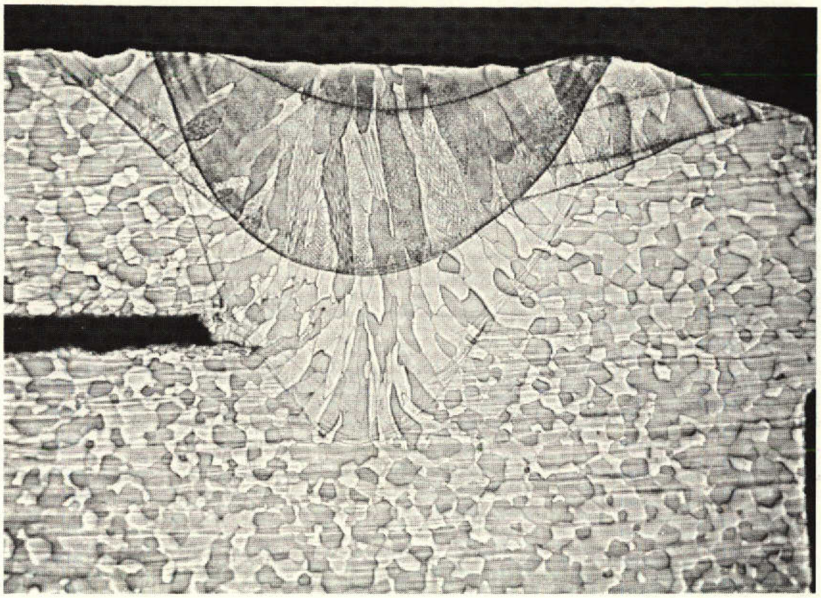
1. Automatic Program - Beam Start Delay - 50%
   Slope - 15%, Start & Final Voltage - 10 KV
   Cam Spacing - 16 Div. (1 to 3)
2. Work Distance - 2"
3. Max. Pressure - 9×10^{-6}

HELIUM LEAK TEST: OK

DYE PENETRANT: OK

W59160

Astronuclear Laboratory



Sample Weld — Procedure 70336-1

Fuel Pin End Cap —Tube (D/2-X) T-111

Procedure No.: 70336-2

Date: 10/8/69

WELDING PROCEDURE

Name of Part Capsule End Cap - Tube (D/2 Size X+Y Config.) Drawing No. NASA-CD-352462-1

Welding Spec. No. ______

Material 304 St. St. Material Spec. No. ______

Description of Welds Covered by this Procedure Shoulder Joint - .062 Min. Penetration (type, size, location) .570" Dia. Tube, X & Y Capsule

Welding Process Electron Beam

Welding Machine Hamilton-Zeiss, 2 KW Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. ______ Spec. ______

Shielding Gas ______ Backup Gas ______

Cleaning Prior to Welding ______

Detailed Procedure:

	Pass	Pass	Pass
Current	3.5 Milliamps		
Voltage	100 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	14 RPM (25 IPM)		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Manual Start & Taper
2. Work Distance - 1 1/2"
3. Deflection - 10 Mil
4. Pressure - $\approx 5 \times 10^{-4}$

HELIUM LEAK TEST OK

DYE PENETRANT OK

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Sample Weld — Procedure 70336-2

Capsule End Cap — Tube (D/2 X & Y) - 304 St. Stl.

Procedure No.: 70336-2"A"

Date: 7/28/70

WELDING PROCEDURE

Name of Part Capsule End Cap - Tube (D/2 Size X & Y Config.) Drawing No. NASA-CD-352462-1

Welding Spec. No. ____

Material 304 St. St. Material Spec. No. ____

Description of Welds Covered by this Procedure Shoulder Joint - .062 Min. Penetration
(type, size, location)
.570" Dia. Tube, X & Y Capsule

Welding Process Electron Beam

Welding Machine Sciaky Type Current ____

Electrode - Type ____ Size ____ Spec. ____

Filler Material - Comp. ____ Spec. ____

Shielding Gas Vac - 1×10^{-4} MM HG (max) Backup Gas ____

Cleaning Prior to Welding Pre-cleaned to assembly checkoff procedure. Handle with clean lint free gloves.

Detailed Procedure:

	Pass	Pass	Pass
Current	50 Milliamps		
Voltage	30 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	50 RPM (600 Pot Setting)		
Interpass Temp.	N.A.		
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Weld Program: 30 KV, Initial Current-5 MA, Final Current-5 MA, Initial & Final Slope -300, Decay-Current & Voltage, Initial & Final Voltage-14, Voltage Slope-2, H.V. Delay-.075 Sec., Motor Delay-0, Travel Speed-50 RPM (constant), Run Time-1.7 Sec., Decay-1.5 Sec.
2. Work Distance - 2" to bottom of scanner coil

HELIUM LEAK OK

DYE PENETRANT OK

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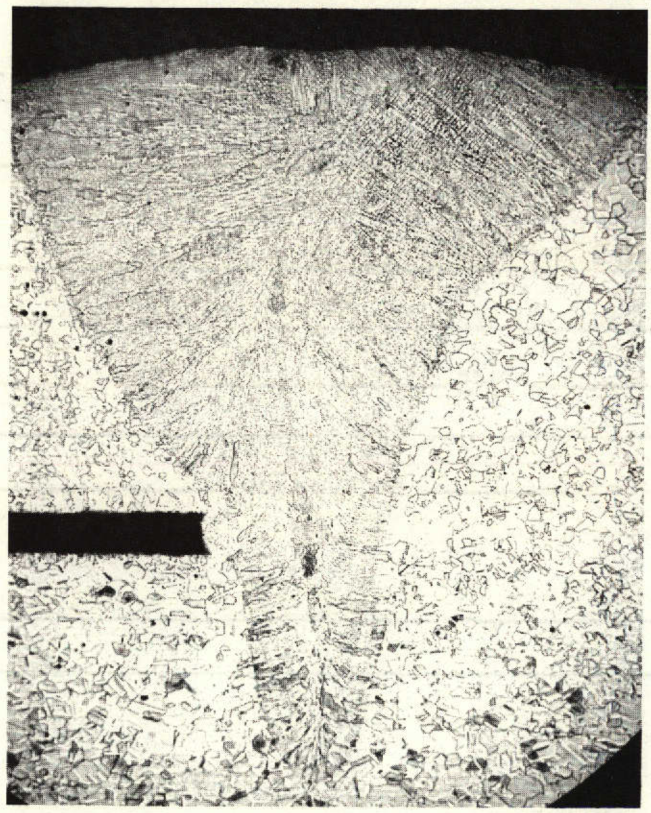

Sample Weld — Procedure 70336-2A

Capsule End Cap — Tube (D/2 X & Y) 304 St. Stl.

Procedure No.: 70336-3

Date: 10/8/69

WELDING PROCEDURE

Name of Part Thermocouple Well (D/2 Size Capsule) Drawing No. NASA-CD-352462-1

Welding Spec. No. ______

Material 304 St. St. to Ta Material Spec. No. ______

Description of Welds Covered by this Procedure Fillet, .090" OD St. St. Tube to .062" OD Tantalum Tube
(type, size, location)

Welding Process Electron Beam

Welding Machine Hamilton-Zeiss, 2 KW Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. ______ Spec. ______

Shielding Gas ______ Backup Gas ______

Cleaning Prior to Welding ______

Detailed Procedure:

	Pass	Pass	Pass
Current	.6 Milliamp		
Voltage	50 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	34 RPM		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1.
2. Work Distance - 6"
3. Beam Location - 80% on St. St.

HELIUM LEAK TEST OK

DYE PENETRANT OK

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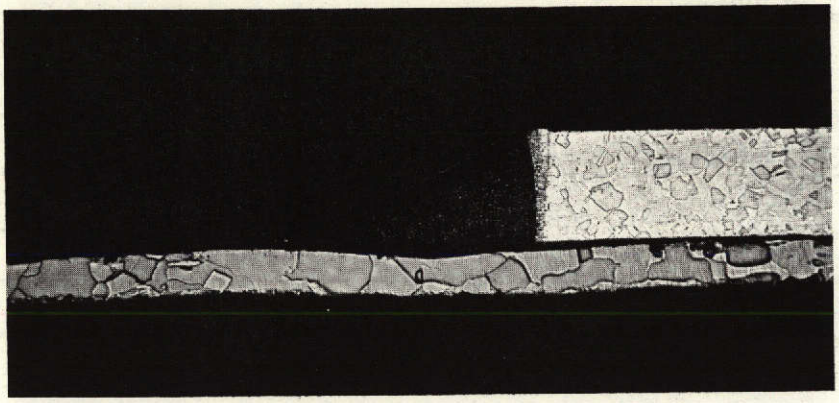

Sample Weld — Procedure 70336-3
Thermocouple Well (D/2) — 304 St. Stl. to Ta.

Procedure No.: 70336-4

Date: 11/11/69

WELDING PROCEDURE

Name of Part Thermocouple Well End Plug (D/2) Drawing No. NASA-CD-352462-1

Welding Spec. No. ____

Material Tantalum Material Spec. No. ____

Description of Welds Covered by this Procedure Edge - Plug inserted flush with end of tube
(type, size, location)

Welding Process Electron Beam

Welding Machine Hamilton-Zeiss, 2 KW Type Current ____

Electrode - Type ____ Size ____ Spec. ____

Filler Material - Comp. ____ Spec. ____

Shielding Gas ____ Backup Gas ____

Cleaning Prior to Welding Handle only with clean, lint free gloves. Will come to weld pre-cleaned. All fixtures or other material contacting the Ta shall be refractory metal (Moly or Ta).

Detailed Procedure:

	Pass	Pass	Pass
Current	1 Milliamp		
Voltage	75 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	34 RPM		
Interpass Temp.			
Weld Position	Beam parallel to tube axis		

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Manual Start & Taper
2. Work Distance - 1"
3. Deflection - None
4. Beam Location - On Joint

HELIUM LEAK TEST OK

DYE PENETRANT OK

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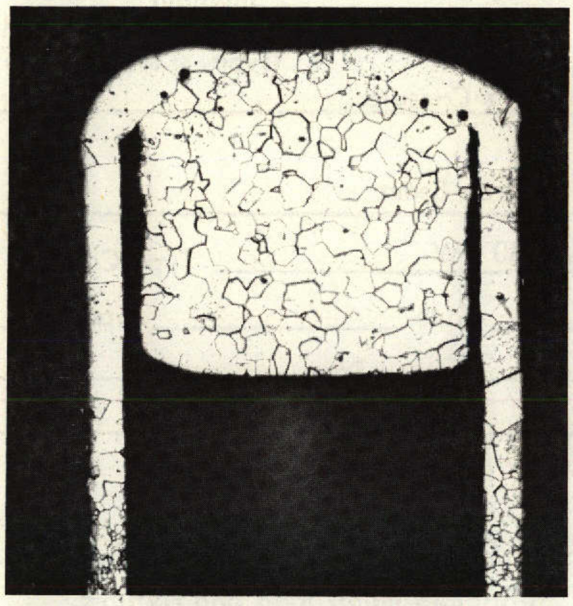

Sample Weld — Procedure 70336-4

Thermocouple Well End Plug — (D/2) Tantalum

Procedure No.: 70336-5

Date: 11/22/69

WELDING PROCEDURE

Name of Part Fuel Pin End Cap - Tube (D/2 Y) Drawing No. NASA-CD-352462-1

Welding Spec. No. ____________

Material T-111 Alloy Material Spec. No. ____________

Description of Welds Covered by this Procedure Shoulder Joint - .021" Min. Penetration (type, size, location)
.375" Dia. Tube - Y Capsule

Welding Process Electron Beam

Welding Machine Sciaky - 30 KW Type Current ____________

Electrode - Type ____________ Size ____________ Spec. ____________

Filler Material - Comp. NONE Spec. ____________

Shielding Gas ____________ Backup Gas ____________

Cleaning Prior to Welding Pickle & degas, handle with lint free gloves, contact only with refractory metal tools and fixtures.

Detailed Procedure:

	Pass	Pass	Pass
Current	35 Milliamps		
Voltage	26 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	60 RPM (910 Pot Setting)		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Automatic Program: Beam Start Delay - 50%
   Slope - 15% Start & Final Volts - 15 KV
   Cam Spacing - 16 Div. (1 to 3)
2. Work Distance - 2"
3. Max. Pressure - 9×10^{-6}

HELIUM LEAK TEST OK

DYE PENETRANT OK

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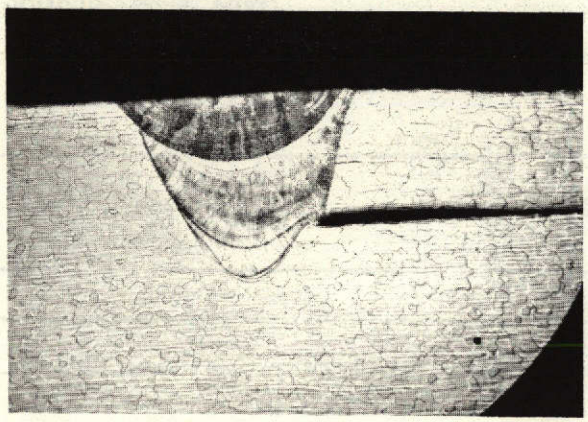

Sample Weld — Procedure 70336-5
Fuel Pin End Cap — Tube (D/2 Y) T-111

Procedure No.: 70336-6

Date: 12/8/69

WELDING PROCEDURE

Name of Part: Capsule End Cap to TC Well (D/2) Drawing No. NASA-CD-352462-1

Welding Spec. No. ____________

Material: 304 St. St. Material Spec. No. ____________

Description of Welds Covered by this Procedure: Shoulder Joint - Penetration Thru End Cap Extension but not into ID of TC Well.
(type, size, location)

Welding Process: Electron Beam

Welding Machine: Hamilton-Zeiss, 2 KW Type Current ____________

Electrode - Type ____________ Size ____________ Spec. ____________

Filler Material - Comp. ____________ Spec. ____________

Shielding Gas ____________ Backup Gas ____________

Cleaning Prior to Welding: Pre-cleaned to assembly checkoff procedure. Handle with clean lint free gloves.

Detailed Procedure:

	Pass	Pass	Pass
Current	1 Milliamp		
Voltage	100 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	34 RPM		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Manual Start & Taper
2. Work Distance - 1 1/2 Inches
3. Pressure - 5×10^{-4} (≈)

HELIUM LEAK TEST OK

DYE PENETRANT OK

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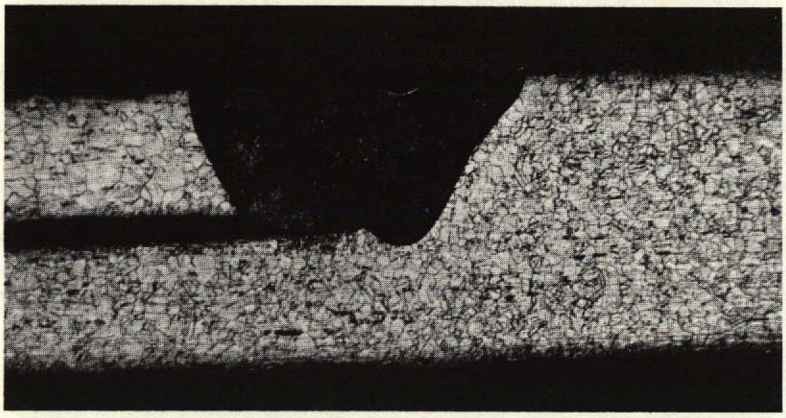

Sample Weld — Procedure 70336-6
Capsule End Cap to TC Well (D/2) 304 St. Stl.

Procedure No.: 70336-7

Date: 10/2/69

WELDING PROCEDURE

Name of Part Capsule End Cap - Tube (D Size X & Y Config.) Drawing No. NASA-CD-352463-1

Welding Spec. No. ______

Material 304 St. St. Material Spec. No. ______

Description of Welds Covered by this Procedure Shoulder Joint (.050 Min. Penetration, .940" Dia. Tube, X Capsule) (.067" Min. Penetration, Y Capsule)
(type, size, location)

Welding Process Electron Beam

Welding Machine Hamilton-Zeiss, 2 KW Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. ______ Spec. ______

Shielding Gas ______ Backup Gas ______

Cleaning Prior to Welding ______

Detailed Procedure:

	Pass	Pass	Pass
Current	10 Milliamps		
Voltage	140 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	34 RPM (100 IPM)		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Manual Start & Taper
2. Work Distance - 6"
3. Pressure - 5×10^{-4} (≈)

HELIUM LEAK TEST OK

DYE PENETRANT OK

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Sample Weld — Procedure 70336-7
Capsule End Cap — Tube (D-X & Y) 304 St. Stl.

Procedure No.: 70336-7"A"

Date: 7/28/70

WELDING PROCEDURE

Name of Part Capsule End Cap - Tube (D Size X & Y Config.) Drawing No. NASA-CD-352463-1

Welding Spec. No. ____

Material 304 St. St. Material Spec. No. ____

Description of Welds Covered by this Procedure (type, size, location) Shoulder Joint (.050 Min. Penetration - X Capsule) (.067 Min. Penetration, Y Capsule), .940" Dia. Tube

Welding Process Electron Beam

Welding Machine Sciaky Type Current ____

Electrode - Type ____ Size ____ Spec. ____

Filler Material - Comp. ____ Spec. ____

Shielding Gas ____ Backup Gas ____

Cleaning Prior to Welding Pre-cleaned to assembly checkoff procedure. Handle with clean lint free gloves.

Detailed Procedure:

	Pass	Pass	Pass
Current	55 Milliamps		
Voltage	30 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	50 RPM (600 Pot Setting)		
Interpass Temp.	N.A.		
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Weld Program: Initial & Final Current-5 Ma, Initial & Final Slope-300, Initial & Final Voltage-14 KV, Decay-Current & Voltage, Voltage Slope-2, H. V. Delay-.075 sec., Motor Delay-0, Travel Speed-50 RPM (constant), Run Time-1.7 sec., Decay-1.5 sec.
2. Work Distance - 2"

HELIUM LEAK TEST OK

DYE PENETRANT OK

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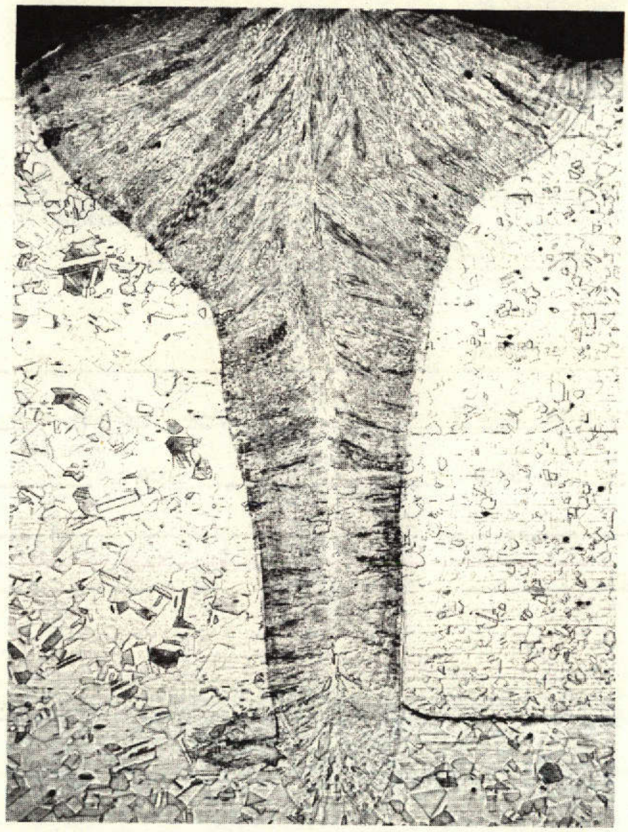


Sample Weld — Procedure 70336-7A

Capsule End Cap — Tube ("D" X & Y) 304 St. Stl.

Procedure No.: 70336-8

Date: 10/8/69

WELDING PROCEDURE

Name of Part: Thermocouple Well (D Size Capsule) Drawing No. NASA-CD-352463-1

Welding Spec. No. ______

Material: 304 St. St. to Tantalum Material Spec. No. ______

Description of Welds Covered by this Procedure (type, size, location): Fillet, .125" OD St. St. Tube to .094" OD Tantalum Tubing

Welding Process: Electron Beam

Welding Machine: Hamilton-Zeiss (2 KW) Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. ______ Spec. ______

Shielding Gas: Vac (10^{-4} Max.) Backup Gas ______

Cleaning Prior to Welding: Handle only with clean lint free gloves after cleaning per assembly procedures.

Detailed Procedure:

	Pass	Pass	Pass
Current	1 Milliamp		
Voltage	50 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	34 RPM		
Interpass Temp.			
Weld Position	Beam parallel to tube axis		

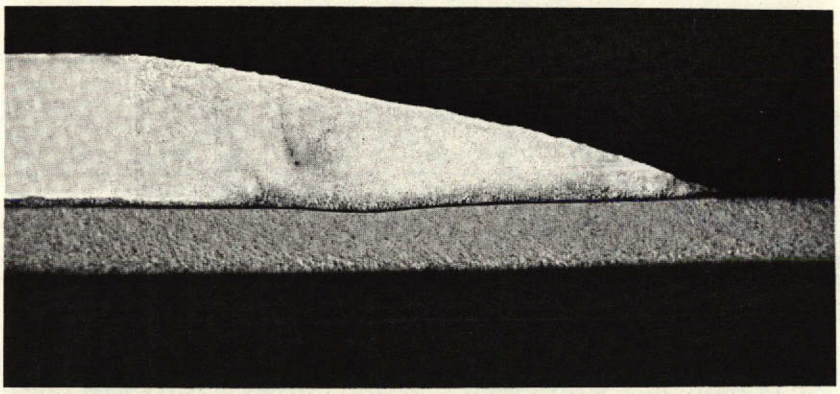
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. 5 Seconds Beam Time
2. Work Distance - 6"
3. Beam Location - 80% of beam cross section on the stainless steel

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



Sample Weld — Procedure 70336-8

Thermocouple Well (D) — 304 St. Stl. - Tantalum

Procedure No.: 70336-9

Date: 11/11/69

WELDING PROCEDURE

Name of Part Thermocouple Well End Plug (D Size Capsule) Drawing No. NASA-CD-352463-1

Welding Spec. No. ______

Material Tantalum Material Spec. No. ______

Description of Welds Covered by this Procedure (type, size, location) Edge-Plug inserted flush with end of .094" OD x .007" wall tube.

Welding Process Electron Beam

Welding Machine Hamilton-Zeiss (2 KW) Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. ______ Spec. ______

Shielding Gas Vacuum (10^{-4} Max.) Backup Gas ______

Cleaning Prior to Welding Handle only with clean lint free gloves. Parts will come to weld area pre-cleaned. Contact only with Moly or Ta tools, fixtures or handling devices.

Detailed Procedure:

	Pass	Pass	Pass
Current	2 Milliamps		
Voltage	75 KV		
Filler Wire Size	N. A.		
Filler Feed Rate	N. A.		
Travel Speed	34 RPM		
Interpass Temp.	N. A.		
Weld Position	Beam parallel to tube axis		

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Manual Start & Taper
2. Work Distance - 1"
3. Deflection - None
4. Beam Location - On Joint

HELIUM LEAK TEST OK

DYE PENETRANT OK

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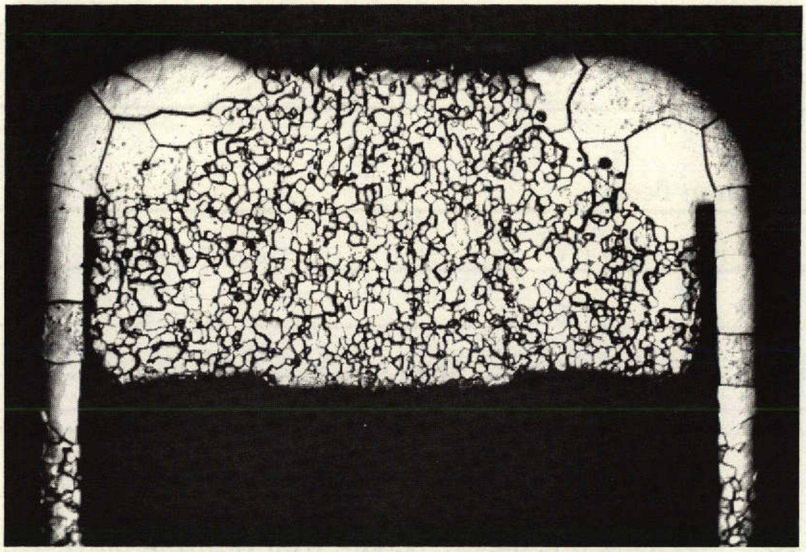


Sample Weld — Procedure 70336-9

Thermocouple Well End Plug (D) Tantalum

Procedure No.: 70336-10

Date: 11/15/69

WELDING PROCEDURE

Name of Part: Fuel Pin End Cap - Tube (D-X) Drawing No. NASA-CD-352463-1

Welding Spec. No. ______

Material: T-111 Alloy Material Spec. No. ______

Description of Welds Covered by this Procedure (type, size, location): Shoulder Joint - .058" Wall Tube to Cap, ≈3/4" Dia.

Welding Process: Electron Beam

Welding Machine: Sciaky - 30 KW Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. ______ Spec. ______

Shielding Gas ______ Backup Gas ______

Cleaning Prior to Welding: Pickle and degas, handle with lint free gloves, contact only with refractory metal tools and fixtures.

Detailed Procedure:

	Pass	Pass	Pass
Current	95-100 Milliamps		
Voltage	20 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	60 RPM (910 Pot Setting)		
Interpass Temp.			
Weld Position			

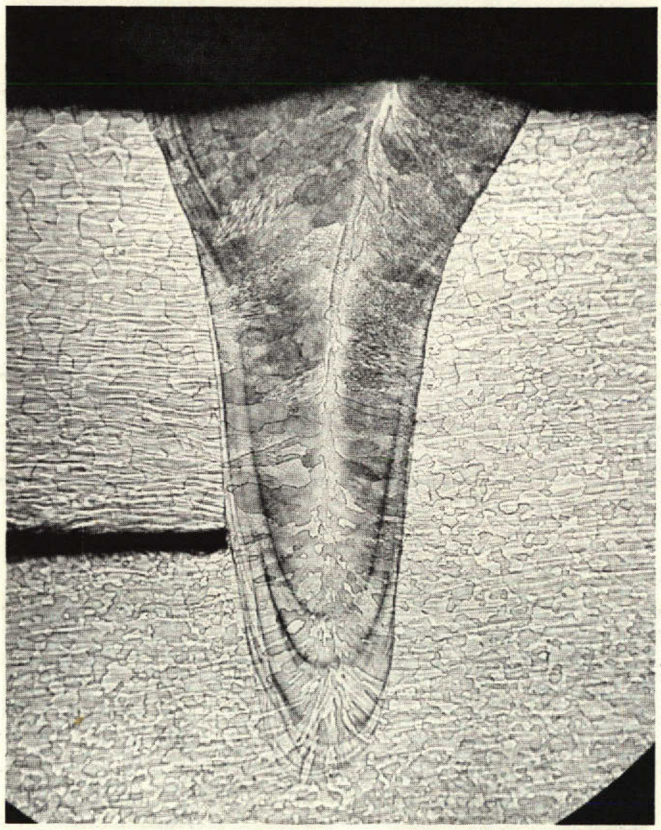
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Automatic Program: Beam Start Delay - 50%
   Slope - 15%, Start & Final Volts - 15 KV
   Cam Spacing - 16 Div. (1 to 3)
2. Work Distance - 2"
3. Max. Pressure - 9×10^{-6}

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



Sample Weld — Procedure 70336-10

Fuel Pin End Cap — Tube (D-X) T-111

Procedure No.: 70336-10A
Date: 3/24/70

WELDING PROCEDURE

Name of Part: Fuel Pin End Cap - Tube (D-X) Requalify   Drawing No. NASA-CD-352463-1

Welding Spec. No. ____

Material: T-111 Alloy   Material Spec. No. ____

Description of Welds Covered by this Procedure: Shoulder Joint - .058" Wall tube to cap ≈3/4" Dia.
(type, size, location)

Welding Process: Electron Beam

Welding Machine: Sciaky - 30 KW   Type Current ____

Electrode - Type ____ Size ____ Spec. ____

Filler Material - Comp. ____ Spec. ____

Shielding Gas ____ Backup Gas ____

Cleaning Prior to Welding: Pickle and degas, handle with lint free gloves, contact only with refractory metal tools and fixtures.

Detailed Procedure:

	Pass	Pass	Pass
Current	65 Milliamps		
Voltage	20 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	15 RPM		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Automatic Program: Beam Start Delay - 50%
   Slope - 15%, Start & Final Volts - 15 KV
   Cam Spacing - 16 Div. (1 to 3)
2. Work Distance - 2"
3. Max. Pressure - 9×10^{-6}

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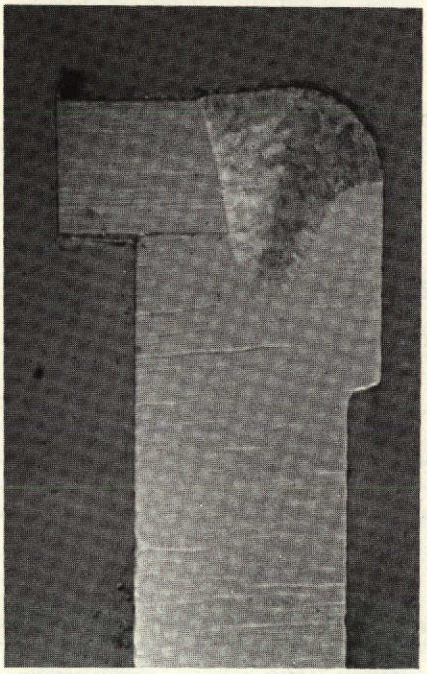


Sample Weld — Procedure 70336-10A
Fuel Pin End Cap — Tube (D-X) T-111

Procedure No.: 70336-11

Date: 11/15/69

WELDING PROCEDURE

Name of Part: Fuel Pin End Cap - Tube (D-Y)   Drawing No. NASA-CD-352463-1

Welding Spec. No. ______

Material: T-111 Alloy   Material Spec. No. ______

Description of Welds Covered by this Procedure (type, size, location): Shoulder Joint - .040" Wall tube to cap, ≈3/4" Dia.

Welding Process: Electron Beam

Welding Machine: Sciaky - 30 KW   Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. ______ Spec. ______

Shielding Gas ______ Backup Gas ______

Cleaning Prior to Welding: Pickle and degas, handle with lint free gloves. Contact only with refractory metal tools and fixtures.

Detailed Procedure:

	Pass	Pass	Pass
Current	90 Milliamps		
Voltage	27 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	60 RPM (910 Pot Setting)		
Interpass Temp.			
Weld Position			

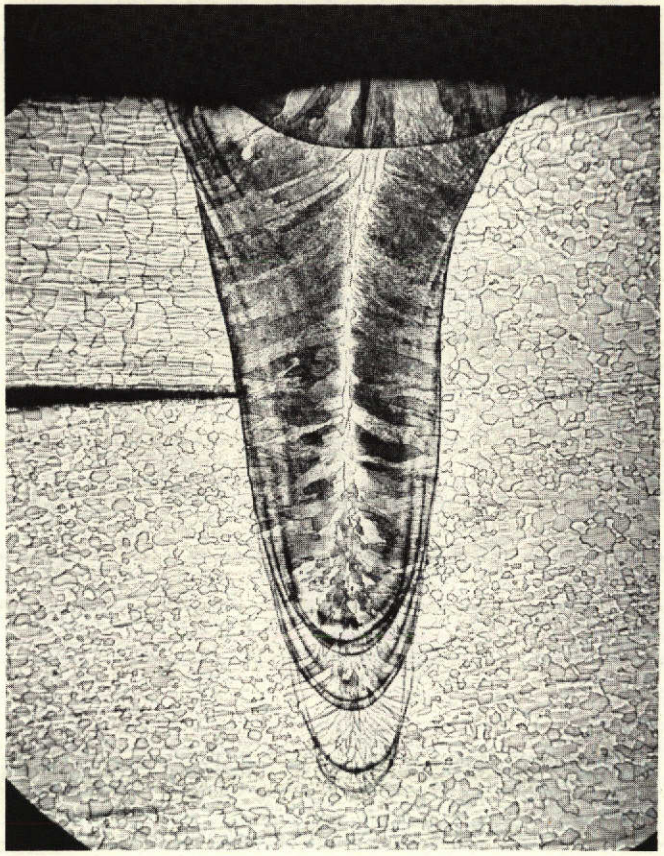
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Automatic Program: Beam Start Delay - 50%
   Slope - 15%
   Start & Final Volts - 15 KV
   Cam Spacing - 16 Div. (1 to 3)
2. Work Distance - 2"
3. Max. Pressure - 9×10^{-6}

HELIUM LEAK TEST OK

W59160

DYE PENETRANT OK



Sample Weld — Procedure 70336-11
Fuel Pin End Cap — Tube (D-Y) T-111

Procedure No.: 70336-11A

Date: 3/24/70

WELDING PROCEDURE

Name of Part: Fuel Pin End Cap - Tube (D-Y) Requalify   Drawing No. NASA-CD-352463-1

Welding Spec. No. ______

Material: T-111 Alloy   Material Spec. No. ______

Description of Welds Covered by this Procedure (type, size, location): Shoulder Joint - .040 Wall tube to cap, ≈3/4" Dia.

Welding Process: Electron Beam

Welding Machine: Sciaky - 30 KW   Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. ______ Spec. ______

Shielding Gas ______ Backup Gas ______

Cleaning Prior to Welding: Pickle and degas, handle with lint free gloves, contact only with refractory metal tools and fixtures.

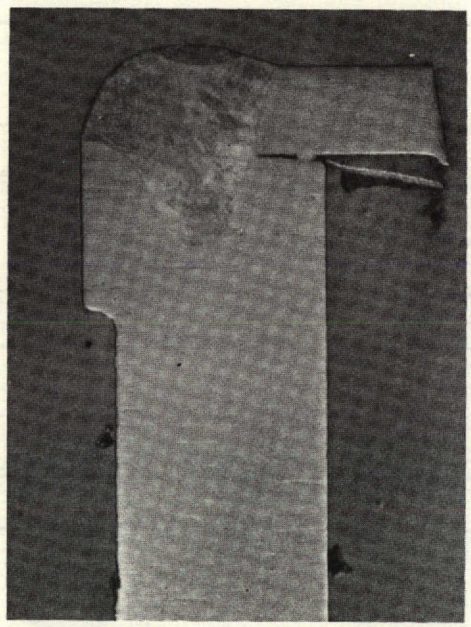
Detailed Procedure:

	Pass	Pass	Pass
Current	65 Milliamps		
Voltage	20 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	15 RPM		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Automatic Program: Beam Start Delay - 50%
   Slope - 15%, Start & Final Volts - 15 KV
   Cam Spacing - 16 Div. (1 to 3)
2. Work Distance - 2"
3. Max. Pressure - 9×10^{-6}

W59160



Sample Weld — Procedure 70336-11A
Fuel Pin End Cap - Tube (D-Y) T-111

Procedure No.: 70336 - 12

Date: 12/1/69

WELDING PROCEDURE

Name of Part Capsule End Cap to T. C. Weld (D) Drawing No. NASA CD-352463-1

Welding Spec. No. ______

Material 304 St. St. Material Spec. No. ______

Description of Welds Covered by this Procedure Shoulder Joint - Penetration thru end cap extension but not into ID of T.C. well
(type, size, location)

Welding Process Electron Beam

Welding Machine Hamilton-Zeiss, 2 KW Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. ______ Spec. ______

Shielding Gas ______ Backup Gas ______

Cleaning Prior to Welding Pre-cleaned to assembly check-off procedure. Handle with clean lint free gloves.

Detailed Procedure:

	Pass	Pass	Pass
Current	1.5 MA		
Voltage	100 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	34 RPM		
Interpass Temp.			
Weld Position			

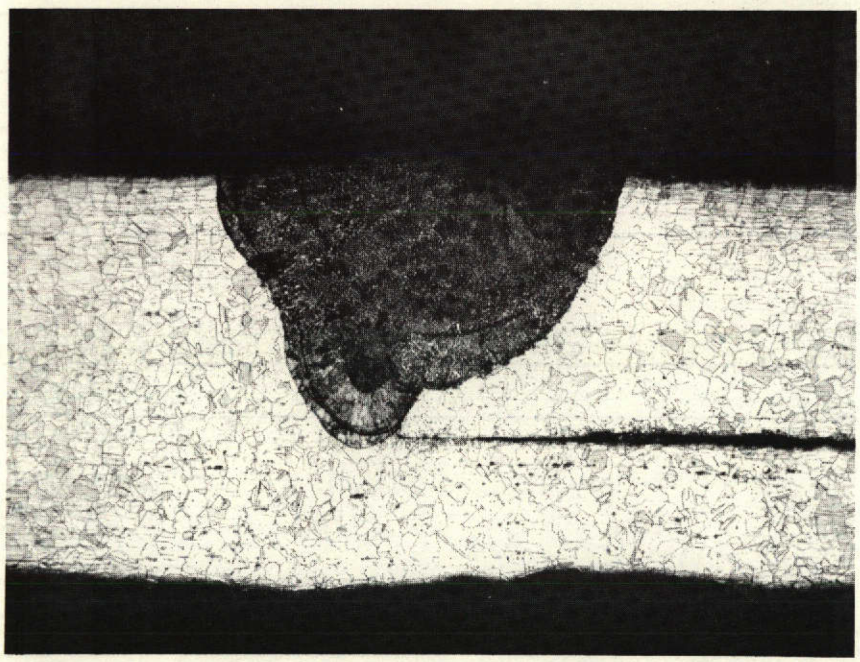
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Manual start and taper.
2. Work distance - 1 1/2 inches.
3. Pressure - 5×10^{-4} ($\approx$)

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



20737A 50X

Sample Weld - Procedure 70336-12
Capsule End Cap to T.C. Well (D) - 304 St. Stl.

Procedure No.: 70336-13

Date: 11/26/69

WELDING PROCEDURE

Name of Part D/2 Fuel Pin Final Seal Weld   Drawing No. NASA CD-352462-1

Welding Spec. No. ______

Material T-111 Alloy   Material Spec. No. ______

Description of Welds Covered by this Procedure Arc spot seal of .030" dia. hole
(type, size, location)

Welding Process Tungsten Arc

Welding Machine Vickers-400 Amp AC-DC(w/Controllor)   Type Current DCSD

Electrode - Type W (2% Thor)   Size 3/32" dia.   Spec. ______

Filler Material - Comp. T-111 Alloy   Spec. ______

Shielding Gas Helium   Backup Gas ______

Cleaning Prior to Welding Pre-cleaned and handled in assembly chamber as defined in check-off procedure.

Detailed Procedure:

	Pass	Pass	Pass
Current	115 amps		
Voltage			
Filler Wire Size	.020		
Filler Feed Rate	Pre-placed		
Travel Speed			
Interpass Temp.			
Weld Position	Torch vertical		

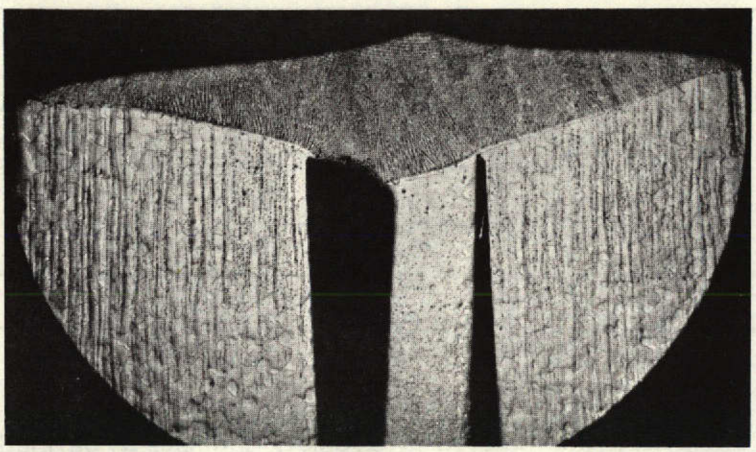
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Arc gap - 1/32"
2. Pre-place .020 dia. filler wire in hole with max. extension of approx. .01".
3. Weld time: < 1/2 sec., Weld taper: 1/2 sec.
4. Electrode preparation: Grind at 30° taper to an approximate .020" tip.

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



20735 30X

Sample Weld - Procedure 70336-13
Fuel Pin Final Seal Weld (D/2) - T-111

Procedure No.: 70336-14

Date: 11/26/69

WELDING PROCEDURE

Name of Part (D) Fuel Pin Final Seal Weld   Drawing No. NASA CD-352463-1

Welding Spec. No. ______

Material T-111 Alloy   Material Spec. No. ______

Description of Welds Covered by this Procedure Arc spot seal of .030" Dia. hole
(type, size, location)

Welding Process Tungsten arc

Welding Machine Vickers 400 Amp AC-DC (w/controller)   Type Current DCSP

Electrode - Type W (2% Thor)   Size 3/32" dia.   Spec. ______

Filler Material - Comp. T-111 Alloy   Spec. ______

Shielding Gas Helium   Backup Gas ______

Cleaning Prior to Welding Pre-cleaned and handled in assembly chamber as defined in check-off procedure.

Detailed Procedure:

	Pass	Pass	Pass
Current	115 amps		
Voltage			
Filler Wire Size	.020		
Filler Feed Rate	Pre-placed		
Travel Speed			
Interpass Temp.			
Weld Position	Torch angled $\approx 20^{\circ}$ over center		

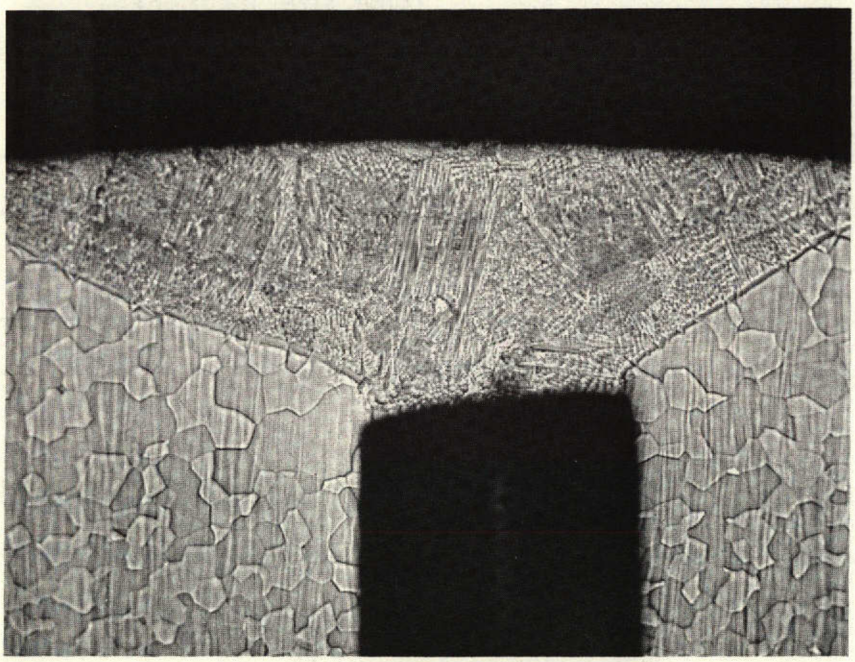
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Arc gap - 1/32"
2. Pre-place .020 dia. filler wire in hole with max. extension of approx. .01".
3. Weld time - 1 1/2 sec., Weld taper - 1/2 sec.
4. Electrode preparation: Grind at 30° taper to an approx. .020" tip.

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



Sample Weld - Procedure 70336-14
Fuel Pin Final Seal Weld (D) - T-111

Procedure No.: 70336-15

Date: 1/16/69

WELDING PROCEDURE

Name of Part D & D/2 Capsule Seal Weld

Drawing No. NASA CD-352463-1
NASA CD-352462-1

Welding Spec. No.

Material 304 St. St.

Material Spec. No.

Description of Welds Covered by this Procedure Arc spot seal of .030" dia. hole.
(type, size, location)

Welding Process Tungsten Arc

Welding Machine Vickers 400 Amp AC-DC (w/controllor)

Type Current DCSP

Electrode - Type   Size   Spec.

Filler Material - Comp.   Spec.

Shielding Gas Helium

Backup Gas

Cleaning Prior to Welding Pre-cleaned and handled in assembly chamber as defined in check-off procedure.

Detailed Procedure:

	Pass	Pass	Pass
Current	30 amps		
Voltage			
Filler Wire Size			
Filler Feed Rate			
Travel Speed			
Interpass Temp.			
Weld Position	Torch angled ≈15°		

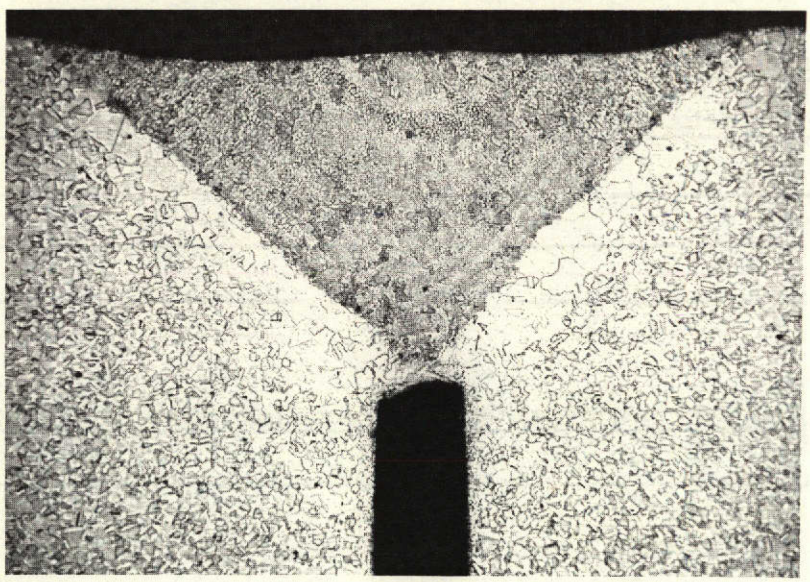
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Arc gap - 1/32"
2. Weld time: < 1/2 sec., Weld taper: 1/2 sec.
3. Electrode Prep: Grind at 30° Taper to an approx. .020" tip.
4. Soft Start: On -.9

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



Sample Weld - Procedure 70336-15
Capsule Final Seal Weld (D & D/2) 340 St. Stl.

Procedure No.: 70336-16

Date: 12/29/69

WELDING PROCEDURE

Name of Part Capsule End Cap T.C. Well (D Size Capsule) Drawing No. NASA 352463-1

Welding Spec. No. ______

Material 304 St. St. Material Spec. No. ______

Description of Welds Covered by this Procedure Edge Weld in .015" Material
(type, size, location)

Welding Process Electron Beam

Welding Machine Hamilton Zeiss, 2 KW Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. ______ Spec. ______

Shielding Gas ______ Backup Gas ______

Cleaning Prior to Welding Cleaning and handling to the requirements of the operations sheet.

Detailed Procedure:

	Pass	Pass	Pass
Current	1 milliamp		
Voltage	100 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	34 RPM		
Interpass Temp.			
Weld Position			

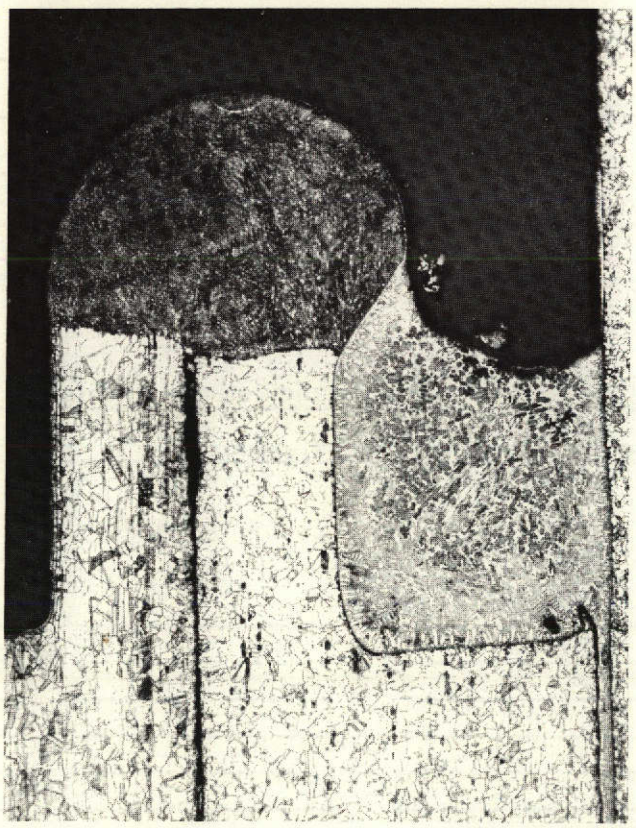
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Manual start and taper.
2. Work distance 1 1/2".
3. Pressure - 5×10^{-4} ($\approx$)
4. Beam shall be parallel to the T. C. well axis. Thermocouple, part No. 17, will be in place at time of welding and must bent to prevent interference with beam.

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



Sample Weld - Procedure 70336-16
Capsule End Cap - T.C. Well (D) - 304 St. Stl.

Procedure No.: 70336-17

Date: 6/8/70

WELDING PROCEDURE

Name of Part Fuel Pin - Fuel Pin Spacer (D/2) Drawing No. NASA CD-352462-1

Welding Spec. No.

Material T-111 Alloy Material Spec. No.

Description of Welds Covered by this Procedure Lap weld between spacer on OD and pin - two tacks approx. 1/16" dia. on each end.
(type, size, location)

Welding Process Electron beam

Welding Machine Sciaky Type Current

Electrode - Type Size Spec.

Filler Material - Comp. None Spec.

Shielding Gas Backup Gas

Cleaning Prior to Welding Material shall have been pickled and degassed. Handle with lint free gloves, contact only with refractory metal tools and fixtures.

Detailed Procedure:

	Pass	Pass	Pass
Current	30 MA		
Voltage	20 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed			
Interpass Temp.			
Weld Position	Pin horizontal		

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Tack weld time - .45 sec, no taper etc.
2. Work distance - ≈4"

W59160

Procedure No.: 70336-18

Date: 6/8/70

WELDING PROCEDURE

Name of Part Fuel Pin - Fuel Pin Spacer (D) Drawing No. NASA CD-352463-1

Welding Spec. No. ______

Material T-111 Alloy Material Spec. No. ______

Description of Welds Covered by this Procedure Lap weld between spacer on O.D. and pin - two
(type, size, location)
tacks approx. 1/16" dia. on each end.

Welding Process Electron beam

Welding Machine Sciaky Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. None Spec. ______

Shielding Gas ______ Backup Gas ______

Cleaning Prior to Welding Pickle and degas. Handle with lint free gloves, contact only with refractory metal tools and fixtures.

Detailed Procedure:

	Pass	Pass	Pass
Current	30 MA		
Voltage	30 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed			
Interpass Temp.			
Weld Position	Pin horizontal		

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Tack weld time: .45 sec, no taper etc.
2. Work distance : $\approx$4"

W59160

Procedure No.: 70336-19

Date: 9/24/70

WELDING PROCEDURE

Name of Part Capsule End Cap - T.C. Well (D) Drawing No. NASA CD-352463-1

Welding Spec. No. ______

Material 304 St. St. Material Spec. No. ______

Description of Welds Covered by this Procedure Shoulder Joint - .028 min. penetration on .180" (type, size, location) on .180" diameter tubular assembly.

Welding Process Electron Beam

Welding Machine Sciaky Type Current ______

Electrode - Type ______ Size ______ Spec. ______

Filler Material - Comp. None Spec. ______

Shielding Gas Vac. -1×10^{-4} mm Hg (max.) Backup Gas ______

Cleaning Prior to Welding Pre-cleaned to assembly check-off procedure. Handle with clean, lint free gloves.

Detailed Procedure:

	Pass	Pass	Pass
Current	6 MA		
Voltage	30 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	50 RPM (600 pot setting)		
Interpass Temp.			
Weld Position	Beam vertical		

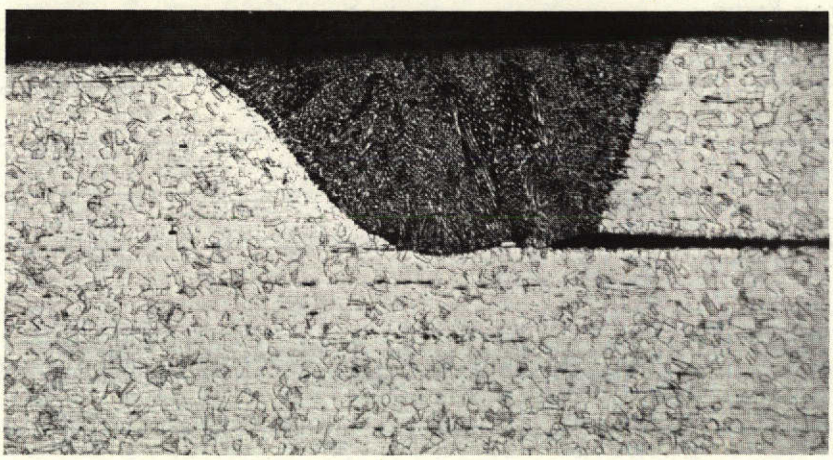
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Weld Program: Initial and final current - 1 MA, Initial and final slope rate - 300, Initial and final voltage - 14 KV, High voltage slope - 1, High voltage start delay - .3 sec., Run time - 2 sec., Decay -.5 sec.
2. Work distance - 2" to bottom of scanner coil.

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



Sample Weld - Procedure 70336-19
Capsule End Cap - T.C. Well (D) - 304 St. Stl.

Procedure No.: 70336-20

Date: 9/24/70

WELDING PROCEDURE

Name of Part Capsule End Cap - T.C. Well (D/2) Drawing No. NASA CD 352462-1

Welding Spec. No.

Material 304 St. Stl. Material Spec. No.

Description of Welds Covered by this Procedure Shoulder Joint - .020 Penetration on .130" diameter tubular assembly.
(type, size, location)

Welding Process Electron Beam

Welding Machine Sciaky (30 KW) Type Current

Electrode - Type Size Spec.

Filler Material - Comp. None Spec.

Shielding Gas Vac. 1×10^{-4} mm Hg Max. Backup Gas

Cleaning Prior to Welding Pre-cleaned to assembly check-off procedure. Handle with clean, lint free gloves.

Detailed Procedure:

	Pass	Pass	Pass
Current	2.5 MA		
Voltage	30 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	50 RPM (600 pot settling)		
Interpass Temp.			
Weld Position	Beam vertical		

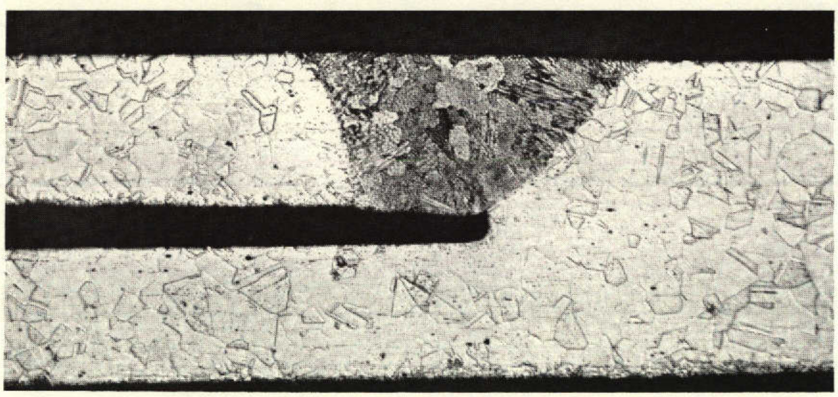
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Weld Program: Initial and final current - 1 MA, Initial and final slope rate - 300, Initial and final voltage - 14 KV, High voltage slope - 1, High voltage start delay - .3 sec., Run time - 1.5 sec., Decay - .5 sec.
2. Work distance - 2" to bottom of scanner coil

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



Sample Weld - Procedure 70336-20
Capsule End Cap - T.C. Well (D 2) - 340 St. Stl.

Procedure No.: 70336-21

Date: 9/24/70

WELDING PROCEDURE

Name of Part: TC Sheath to TC Well (D) Drawing No. NASA CD-352463-1

Welding Spec. No.

Material: 340 St. St. Material Spec. No.

Description of Welds Covered by this Procedure (type, size, location): Lap weld between .015" - .010" thick outer wall of TC well and .090"-.125" TC Sheath.

Welding Process: Electron Beam

Welding Machine: Sciaky Type Current

Electrode - Type Size Spec.

Filler Material - Comp. None Spec.

Shielding Gas: Vac - 1 x 10^{-4} mm Hg (Max.) Backup Gas

Cleaning Prior to Welding: Pre-cleaned to assembly check-off procedure. Handle with clean, lint free gloves.

Detailed Procedure:

	Pass	Pass	Pass
Current	2 MA (max.)		
Voltage	17 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	50 RPM (600 pot setting)		
Interpass Temp.	Beam vertical		
Weld Position			

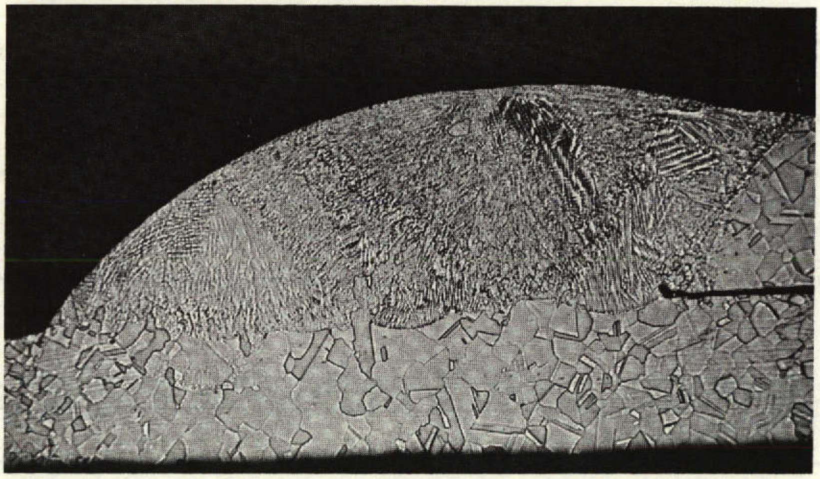
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Run beam on larger diameter at reduced filament current. As preheat occurs and edge melting begins, gradually increase filament current to achieve maximum beam current and move part to blend molten metal onto sheath. As soon as filleting occurs quickly taper beam using filament current control

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



Sample Weld - Procedure 70336-21
TC to TC Well (D) - 304 St. Stl.

Procedure No.: 70336-22

Date: 9/24/70

WELDING PROCEDURE

Name of Part TC Sheath to TC Well (D/2) Drawing No. NASA CD 352462-1

Welding Spec. No.

Material 304 St. Stl. Material Spec. No.

Description of Welds Covered by this Procedure Lap weld between .010" thick outer wall of TC well and .062" dia. (.008" wall) TC sheath.
(type, size, location)

Welding Process Electron Beam

Welding Machine Sciaky Type Current

Electrode - Type Size Spec.

Filler Material - Comp. None Spec.

Shielding Gas Vac - 1 x 10^{-4} mm Hg Backup Gas

Cleaning Prior to Welding Pre-cleaned to assembly check-off procedure. Handle with clean, lint free gloves.

Detailed Procedure:

	Pass	Pass	Pass
Current	1.5 MA (max.)		
Voltage	17 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	50 RPM (600 pot setting)		
Interpass Temp.			
Weld Position	Beam Vertical		

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Run beam on larger diameter at reduced filament current. As preheat occurs and edge melting begins, gradually increase filament current to achieve maximum beam current and move part to blend molten metal onto sheath. As soon as filleting occurs qucikly taper beam using filament current control.

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160

Sample Weld - Procedure 70336-22
TC to TC Well (D/2) - 304 St. Stl.

Procedure No.: 70336 - 23

Date: 9/24/70

WELDING PROCEDURE

Name of Part TC Adapter - End Cap (D) Drawing No. NASA CD-352463-1

Welding Spec. No. ____

Material 340 St. Stl. Material Spec. No. ____

Description of Welds Covered by this Procedure Butt Weld - 1/32" penetration in .180" circle
(type, size, location)

Welding Process Electron Beam

Welding Machine Sciaky Type Current ____

Electrode - Type ____ Size ____ Spec. ____

Filler Material - Comp. None Spec. ____

Shielding Gas Vac. - 1×10^{-4} mm Hg (max.) Backup Gas ____

Cleaning Prior to Welding Pre-cleaned to assembly check-off procedure. Handle with clean, lint free gloves.

Detailed Procedure:

	Pass	Pass	Pass
Current	8 MA		
Voltage	30 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	35 RPM		
Interpass Temp.			
Weld Position	Beam vertical Plane of weld - horiz.		

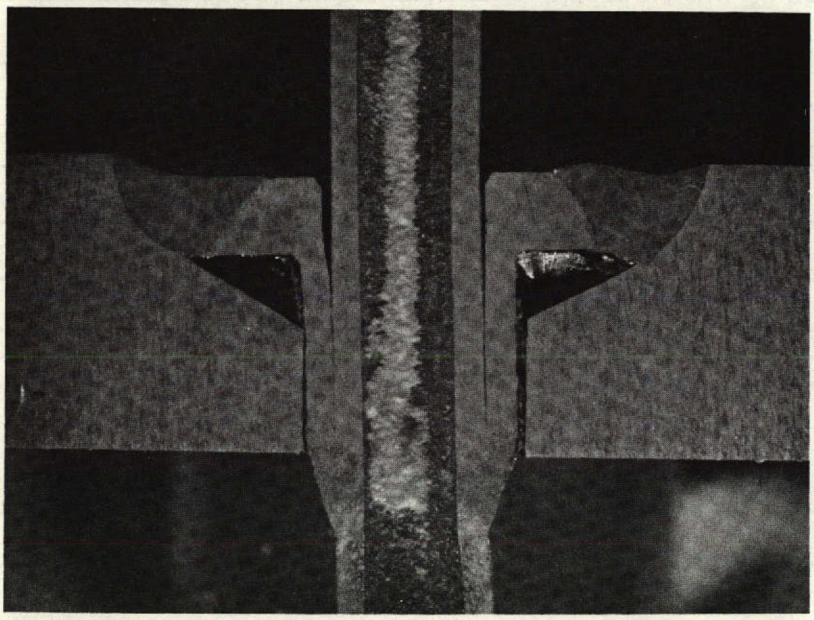
Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Weld Program: Initial and final current - 1 MA, Initial and final slope rate - 300, Initial and final voltage - 14 KV, High voltage slope - 1, High voltage start delay - 0, Run Time - 2.3sec. Decay - .5 sec.
2. Work distance - 1.5" to bottom of scanner coil.

HELIUM LEAK TEST OK

DYE PENETRANT OK

W59160



Sample Weld - Procedure 70336-23
TC Adapter - End Cap (D) - 304 St. Stl.

Procedure No.: 70336-24

Date: 11/14/70

WELDING PROCEDURE

Name of Part: Fuel Pin End Cap - Tube (D/2 X & Y) (Requalify with triode gun) Drawing No. NAS CD-352462-1

Welding Spec. No. ____

Material: T-111 Alloy Material Spec. No. ____

Description of Welds Covered by this Procedure (type, size, location): Shoulder Joint - .029" min. Penetration - .373 and .359 dia. tube.

Welding Process: Electron Beam

Welding Machine: Sciaky - 30 KW with triode gun Type Current ____

Electrode - Type ____ Size ____ Spec. ____

Filler Material - Comp. None Spec. ____

Shielding Gas ____ Backup Gas ____

Cleaning Prior to Welding: Pickle and degas, handle with lint free gloves, contact only with refractory metal tools and fixtures.

Detailed Procedure:

	Pass	Pass	Pass
Current	35 MA		
Voltage	30 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	50 RPM		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Automatic Program: Initial and final current 5 MA, Initial and final voltage 14 KV, Initial current slope 300, Final current slope 900, Voltage slope 2, H. V. delay .075 sec. , motor delay 0, run time 2.5 sec., delay time 2.0 sec.
2. Work distance $\simeq$2.0"
3. Max. Pressure - 9×10^{-6} torr

HELIUM LEAK TEST: OK

DYE PENETRANT: OK

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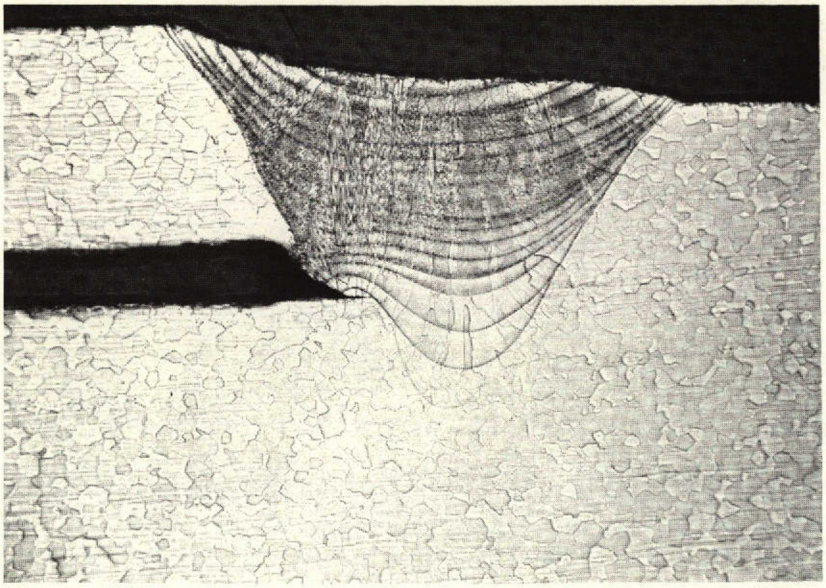


Sample Weld - Procedure 70336-24
Fuel Pin End Cap - Tube (D/2 X & Y) T-111

B. Brazing

The brazing procedure sheet required for brazing thermocouples into capsules is attached. As with welding two sample parts must be produced with the final parameters to demonstrate capability. Braze quality is monitored by visual, radiographic and helium leak test inspections.

Procedure No.: 70336-B-1
Date: 4/17/71

BRAZING PROCEDURE

Drawing No. - CD-352462-1 and CD-352463-1

Braze Description - Thermocouple to Thermocouple Well
D and D/2 Size

Braze Technique - Induction Heating in an Inert Gas (Helium)

Braze Alloy - Nicrobraze 50 (ASTM-B-260 CLB Ni-7)

1. Alloy powder mixed with Nicrobraze cement and a small fillet applied to joint.

2. Coil - 3 turns, 1/2" I.D., 1/2" length for D/2 size
   3 turns, 1" I.D., 1/2" length for D Size

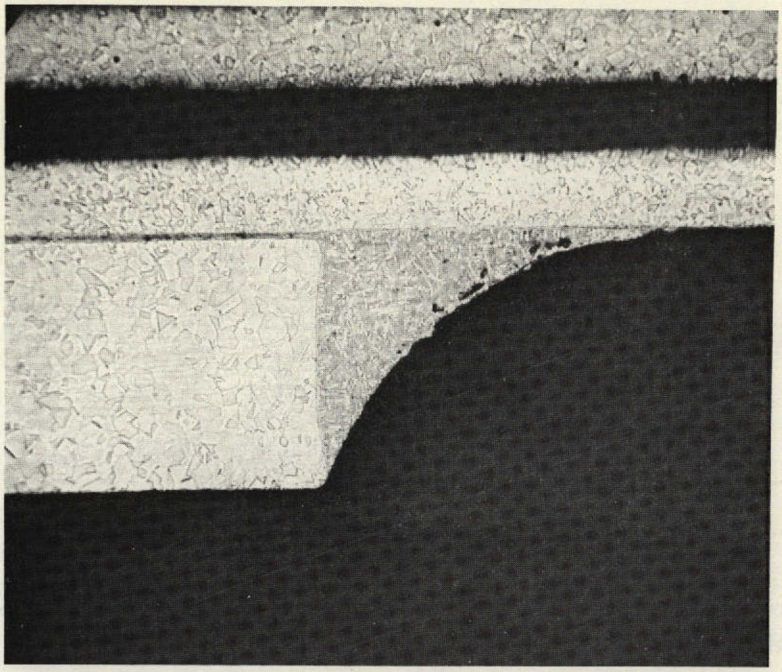
3. Locate shoulder in middle of lower turn of coil.

4. Use minimum power and heat slowly until close to melting point. Increase current slowly until melt occurs. When melting and filleting are observed, turn off power.

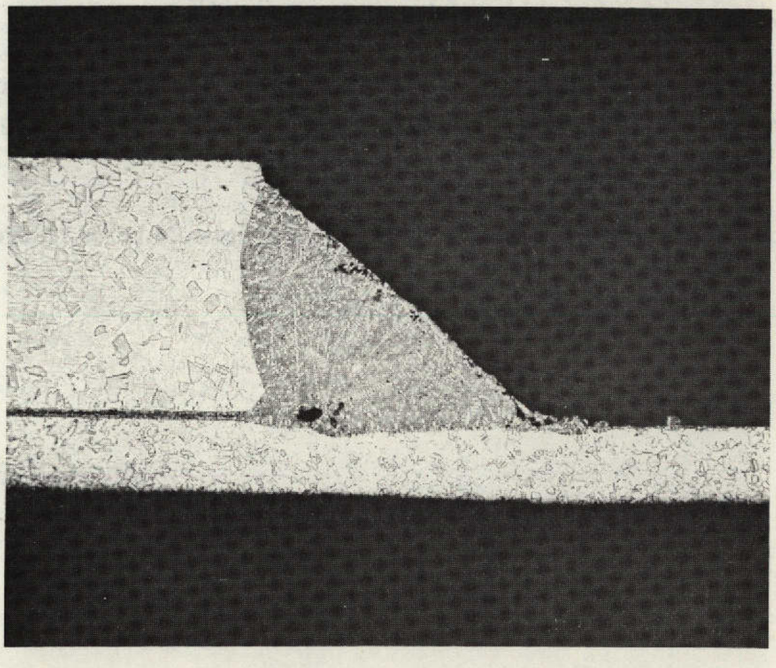
5. Evacuate braze chamber and backfill with helium prior to brazing.

HELIUM LEAK TEST OK

DYE PENETRANT N.A.



Braze No. 1



40 X

Braze No. 2

Figure 16. Development Braze Thermocouple to Thermocouple Well - Procedure 70336-B-1

APPENDIX J

SPECIAL BRAZING DEVELOPMENT

Induction brazing of thermocouples into capsule thermocouple wells using nicrobraz 50 alloy resulted in brittle joints, a high percentage of which were not leak tight. Rebrazing in many instances did not produce leak tight joints and when it did the joint was even more brittle due to excessive alloying of the braze material with the thermocouple sheath.

The thermocouple installation into the capsule was the final assembly step. Hence, a defective braze required machining away the end cap and replacing with a new end cap thermocouple well subassembly. This represented excessive work so the procedure was changed and the thermocouple was brazed into the thermocouple well - end cap subassembly before welding to the capsule. Several sample brazes were made and destructively examined in order to evaluate the brazing procedure, brazing parameters and different batches of nicrobraz 50 alloy. Temperature and other variables were carefully monitored and each joint was mass spec leak tested and visually examined when completed. None of the sample brazes had detectable leaks, however surface porosity was noted on several.

Figures J-1 and J-2 are typical micro-photographs of sample D/2 thermocouple to capsule braze joints using nicrobraz 50 batches No. 123 and 145 braze alloy. No significant difference was noted between the batches of alloy. In all cases the braze material attacked the thermocouple sheath to some degree with penetration of as much as 80 to 90% as indicated in Figure J-3.

In an attempt to improve the brazing technique, a stainless steel washer with approximately the same OD and ID as the thermocouple well was installed in the braze area, Figure J-4. It was theorized that this washer would distribute the heat more evenly, allow a non-critical area of stainless steel to alloy with the braze material and provide a method for applying a constant amount of braze alloy to the joint. Figures J-5, J-6, J-7, J-8, J-9 and J-10 are microphotographs of sample braze joints of D/2 size thermocouples to capsules incorporating the stainless steel washer. All of the sample joints were leak tight. However, it is obvious that the braze material attached the thermocouple sheath as well as the washer. Figures J-9 and J-10 are samples that were rebrazed after initial brazing. As expected, the alloying of braze material with the stainless steel is much more severe when rebrazed but a leak tight joint was accomplished.

In actual capsules, there was a high incidence of leaks at the joints which had to be reworked. Although the braze samples were intended to duplicate the actual braze joints on the capsules as closely as possible, they differed in two important ways: (1) The section of thermocouple used in braze samples did not have the lengths used in the capsule and, (2) The sample brazes were not made into a closed thermocouple well. This could account for the improved leak tightness of the sample brazes over the actual capsule brazes.

In summary, induction brazing with nicrobraz alloys of thin wall thermocouples in the configuration and within the constraints of the capsule program, proved to be a difficult and inconsistent process. Many of the braze joints were not leak tight resulting in time consuming and expensive rework and all are very brittle. It must be pointed out, however, that a considerable number of satisfactory joints have been achieved using this process before the joint was requalified for EB welding.

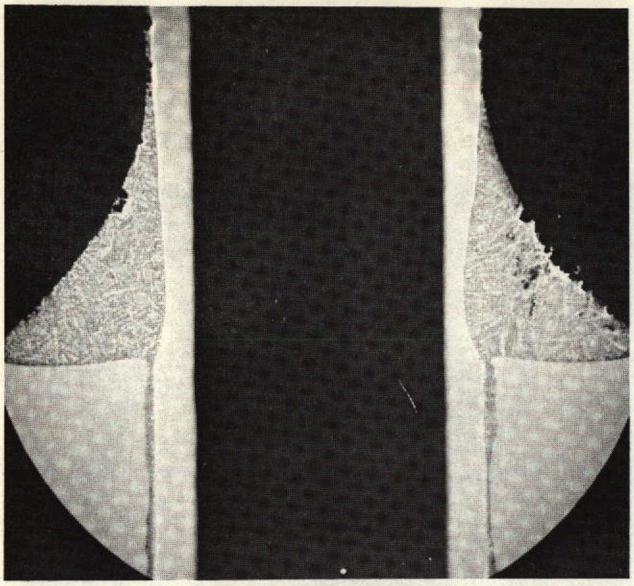


Figure J-1. Sample Braze D/2 Size Thermocouple To Well 25X

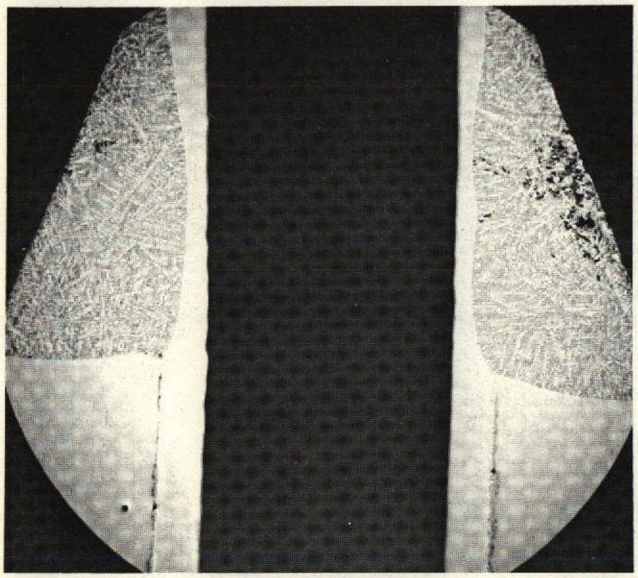


Figure J-2. Sample Braze D/2 Size Thermocouple To Well 25X

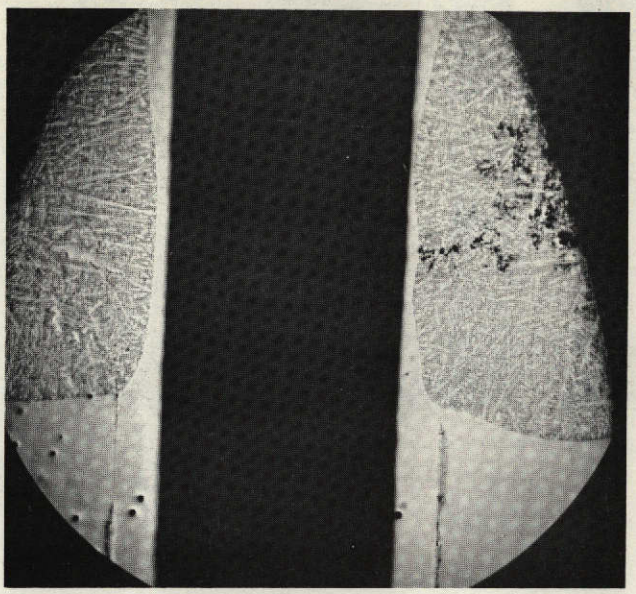


Figure J-3. Sample Braze D/2 Size Thermocouple To Well 25X

Before Braze

After Braze

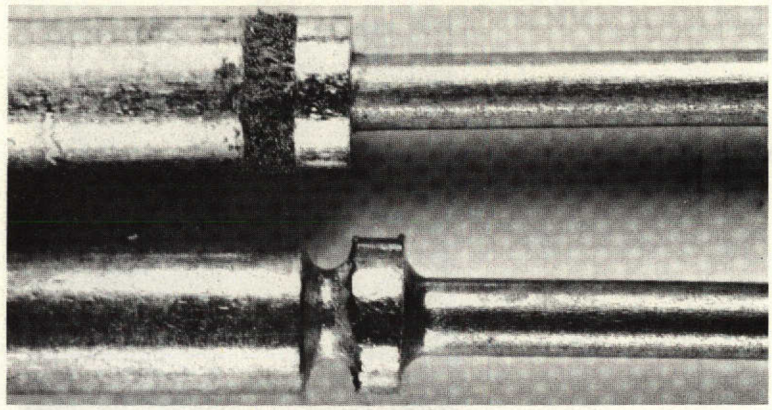


Figure J-4. Sample Braze D/2 Size Thermocouple to Well With Stainless Steel Washer ~6X

Washer

Thermocouple Well

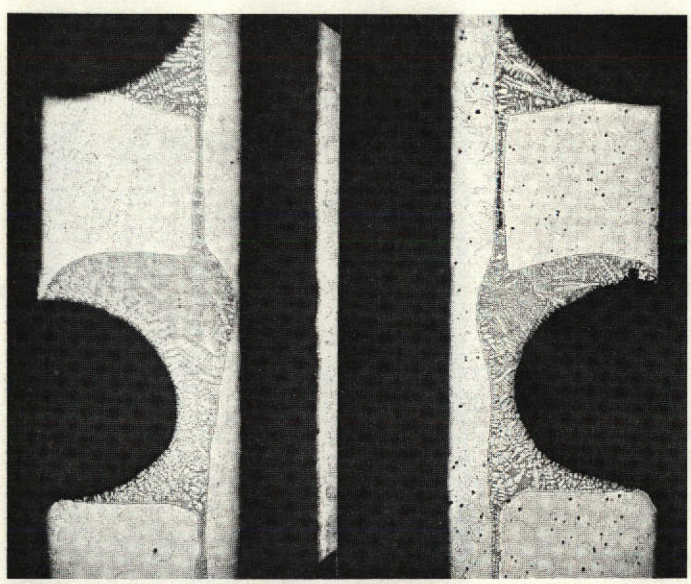


Figure J-5. Sample Braze With Washer D/2 Size Thermocouple to Well 25X

Washer

Thermocouple Well

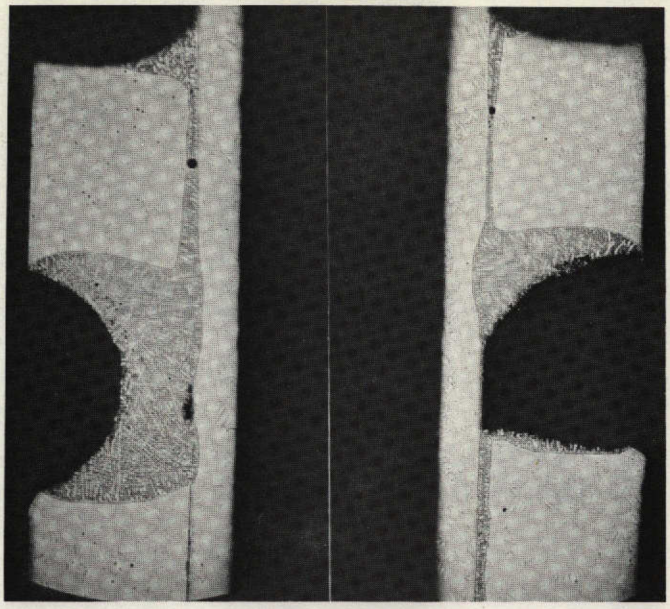


Figure J-6. Sample Braze With Washer D/2 Size Thermocouple to Well 25X

Washer

Thermocouple Well

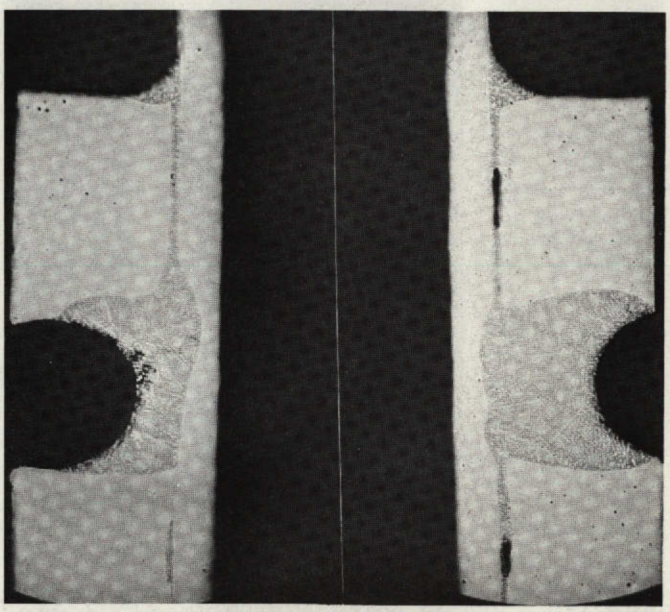


Figure J-7. Sample Braze With Washer D/2 Size Thermocouple to Well 25X

Washer

Thermocouple Well

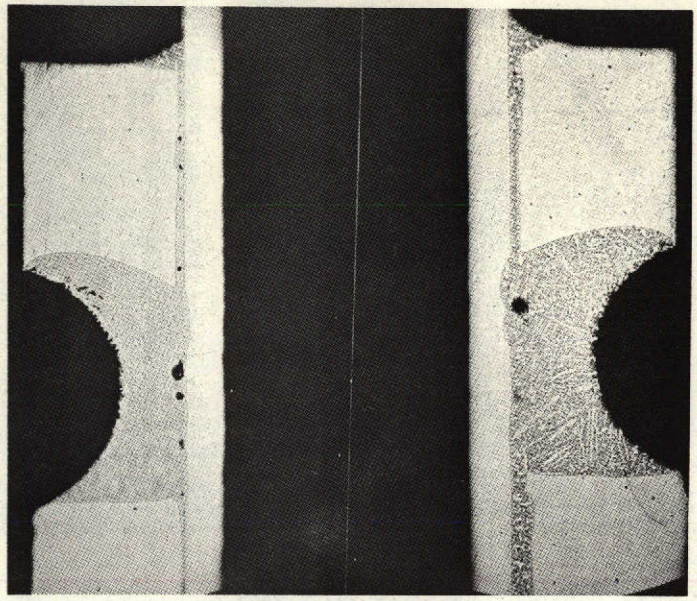


Figure J-8. Sample Braze With Washer D/2 Size Thermocouple to Well 25X

Washer

Thermocouple Well

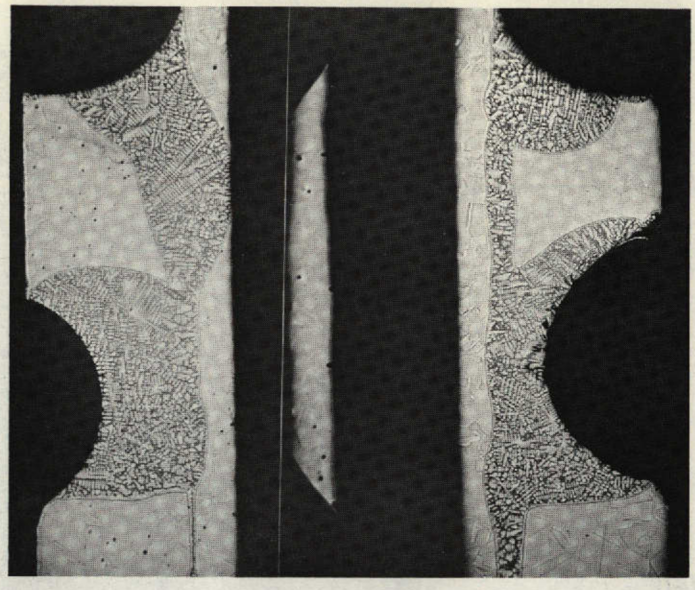


Figure J-9. Sample Rebraze With Washer D/2 Size Thermocouple to Well 25X

Washer

Thermocouple Well

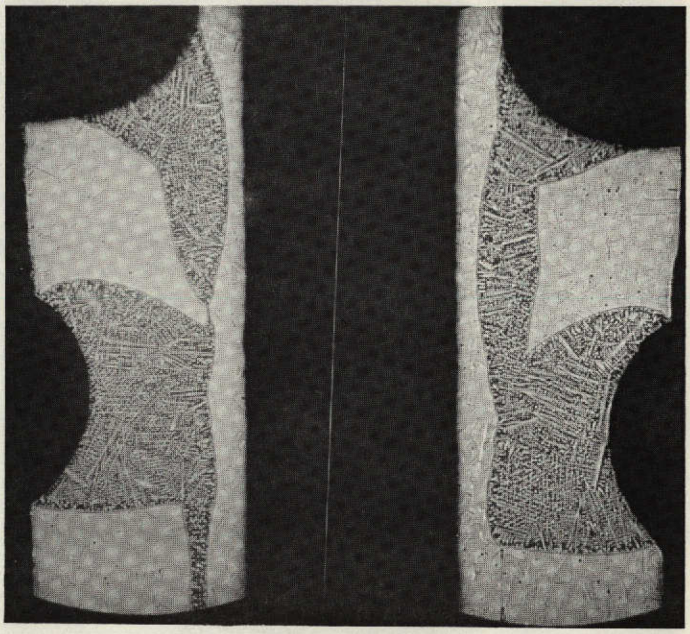


Figure J-10. Sample Rebraze With Washer D/2 Size Thermocouple to Well 25X

APPENDIX K

EVALUATION OF ROOT DEFECTS IN EB WELDS

Background

Radiographic examination of assembled fuel pins was performed as a standard in process inspection step. While designed primarily to record the position of fuel pellets and other internal parts, the radiographs were carefully reviewed for possible use as a weld quality evaluation. Early in the program, it was found that on D size fuel pins 504A and 504B that faint indications of unknown origin were present in the weld joint between the T-111 end cap and tube wall.

Procedure qualification welds produced and tested to arrive at the approved weld schedule had not contained any apparent defects, however, welds were not sectioned longitudinally, which is necessary to detect this kind of a defect. In addition, the production welds on the particular fuel pins in question had passed both dye penetrant and helium leak testing.

To establish the nature of the x-ray indication an extensive metallographic evaluation was performed on production and newly produced, sample joints. The confirmation of the presence of an actual weld root defect which was obtained led to the development of a new weld procedure. Careful analysis of additional sample joints and inspection of subsequently produced production parts indicates that the defect has been eliminated. In contrast with the D size closures it should be noted that the end cap welds in the D/2 size fuel pins were closely examined by both x-ray and metallographically and no defects of any type were observed. A series of typical longitudinal weld sections are shown in Figure K-1 illustrating the freedom from porosity or other root voids in D/2 fuel pin end plug closures.

Weld Defect Analysis

Fuel pin 504A was selected for destructive analysis since it contained the most apparent defects as indicated by the available radiographs. An additional sample joint was also produced with the standard weld procedure and it too was destructively examined. These welds were re-examined radiographically in a number of orientations and were metallographically sectioned both in the transverse and longitudinal direction.

Defects were found in all three welds at the root of the penetration area. Figures K-2, K-3, K-4, and K-5 are typical weld cross sections showing the characteristics and position of the root voids.

The type of cold shutting and porosity observed was typical of that which occurs in many partial penetration electron beam welds with high depth to width ratios. In this particular case the weld parameters were apparently such that small variations in beam focus or other operating characteristic caused large differences in the size and number of defects which would occur. The variation observed is illustrated by the sections shown in Figures K-6 and K-7 which compare a sample weld with the originally questioned production joint from fuel pin 504A

All the defect analysis performed indicated that the voids and cold shuts were concentrated in the very narrow bottom of the fused weld area. Rapid chilling and high welding speeds prevented the molten metal from flowing back into the cavity formed by the electron beam as the weld was being produced. General weld penetration, however, was much greater than the wall thickness of the fuel pin tube. Thus, all defects were restricted to an area below that required for the basic weld joint thickness.

Even though there was no evidence that the weld strength or performance would be affected, it was considered necessary to eliminate the root voids. The non-destructive radiographic examination possible on production fuel pins could only show the presence of voids but could not pinpoint them as to circumferential location or depth. Thus, to assure maximum reliability a development program was performed to establish improved weld parameters from which no root defects would occur.

New Procedure Qualification

Two approaches were used in an attempt to eliminate the defects resulting from the very sharp, deep penetration welding mode. Electron beam focus above rather than at the work piece reduces the energy density (thus beam penetrating power) and smoothes the weld root. Decreased welding speed (with corresponding decrease of welding power) also smoothes the weld root by reducing chilling effects. Both techniques widen the weld face and result in more total heat input for a given required penetration level.

A series of welds were produced with variations in weld parameters designed to increase the weld width at the root of the fusion area. Bead-on-tube welds were used as a first step to arrive at approximate weld energy settings for a given speed-focus condition. Simulations of actual end cap to tube welds were employed for final checking of a given procedure. These latter samples were similar to production parts with regard to mass and dimensions in the immediate weld area.

The following table lists a number of weld conditions which were evaluated. Photographs of the conditions noted are included in this report.

Experimental Welding Conditions for D Size Fuel Pins

	Electron Beam			
	Current milliamp	Voltage KV	Focus	Weld Speed
Original Weld Settings	95-100	27-28	Sharp	66 RPM
Condition A	98	28	Defocused	60 RPM
Condition B	80	24	Sharp	24 RPM
Condition C	90	25	Defocused	24 RPM
Condition D	65	20	Sharp	15 RPM

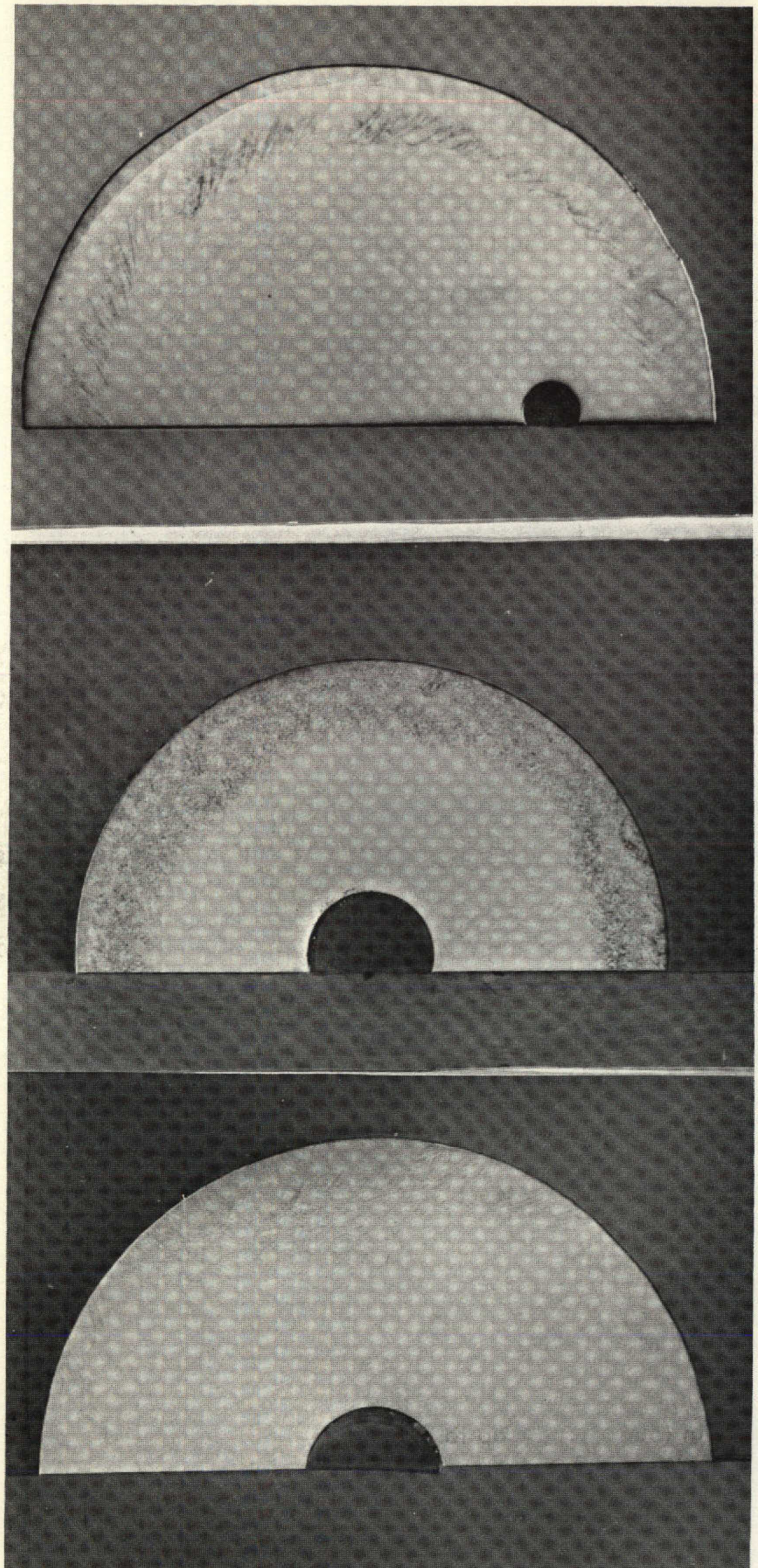
Slight decrease from the standard welding speed and a defocused beam (Condition A) resulted in a weld fusion zone with a more rounded weld penetration profile. Sectioning longitudinally, however, showed that a considerable amount of deep "spiking" of the beam was still present, see Figure K-8. Voids and cold shuts accompanied these local, heavy penetration areas.

Welding with the parameters listed as Condition B produced a much smoother joint profile without the deep penetration spikes noted when welding at higher speeds. As expected, far fewer root defects were present than in other welds. Figure K-9 shows the typical configuration and quality of these joints. In an attempt to eliminate even the minor defects still present, similar welds were made with a defocused beam (Condition C). In this latter case no voids could be found but some very minor cold shutting was still present.

Speed and power were reduced still further to 15 RPM as noted for Condition D. These parameters gave very smooth penetration with no observable defects. Choosing this condition as the standard for future welding, a series of 6 sample joints were produced and evaluated. No root defects of any type could be observed when the joints were destructively examined. These welds were produced with fixturing and chilling effect very similar to that for an actual fuel pin.

Figure K-10 shows sections of a typical weld produced with the low speed parameters. On a macro scale it can be seen that the very edge of the assembly has melted and became part of the overall fusion zone. Some outer diameter build up occurs as a result of this more extensive melting but in no case has it exceeded approximately .010 inches.

Production units were welded with the new procedure. Inspection by visual, dye penetrant, helium leak test and radiographic techniques has shown no defects of any type.



12X

Sample Weld

11X

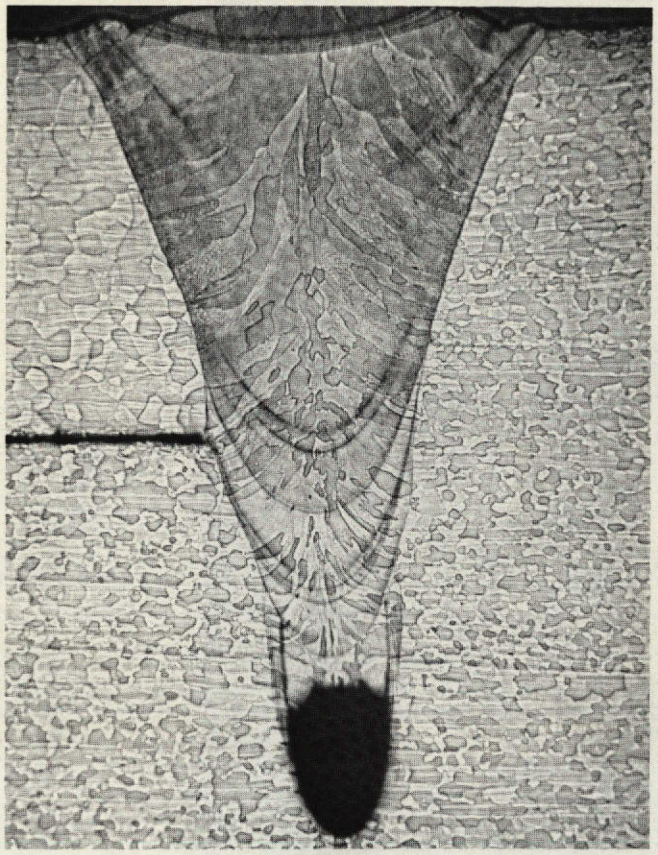
D-3 Fuel Pin

12X

D-5 Fuel Pin

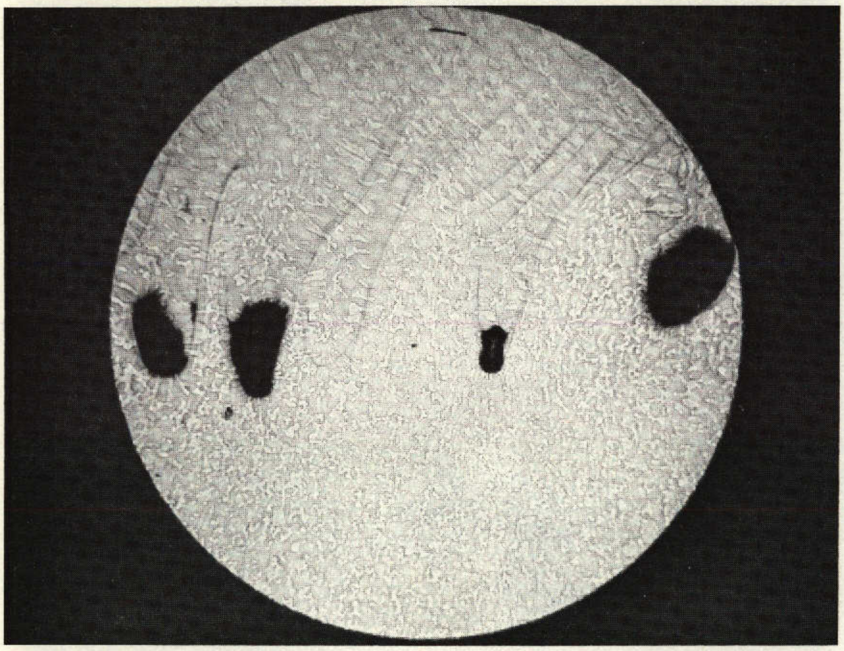
Figure K-1. Typical Longitudinal Sections of D/2 Size T-111 Fuel Pin End Plug Closures

Tube Wall



50X

Figure K-2. T-111 Fuel Pin (504A) End Cap to Tube Electron Beam Weld - Transverse Section



25X

Figure K-3. T-111 Fuel Pin (504A) End Cap to Tube
Electron Beam Weld - Longitudinal Section in Root Area

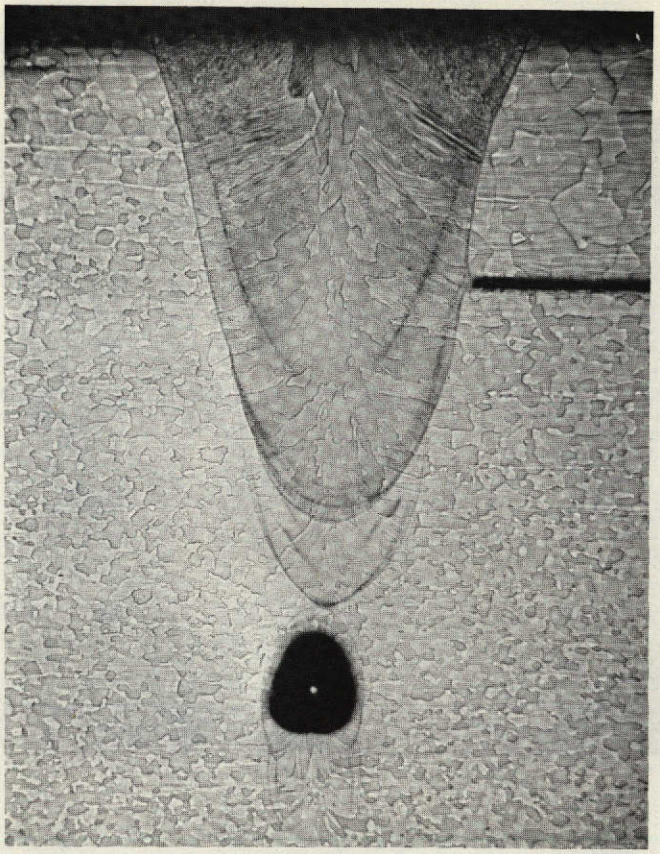
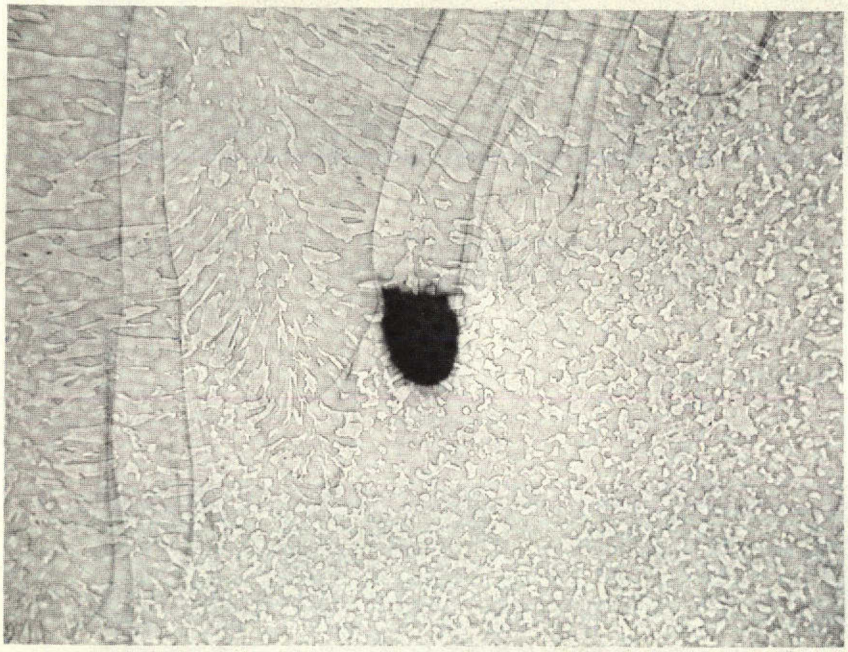
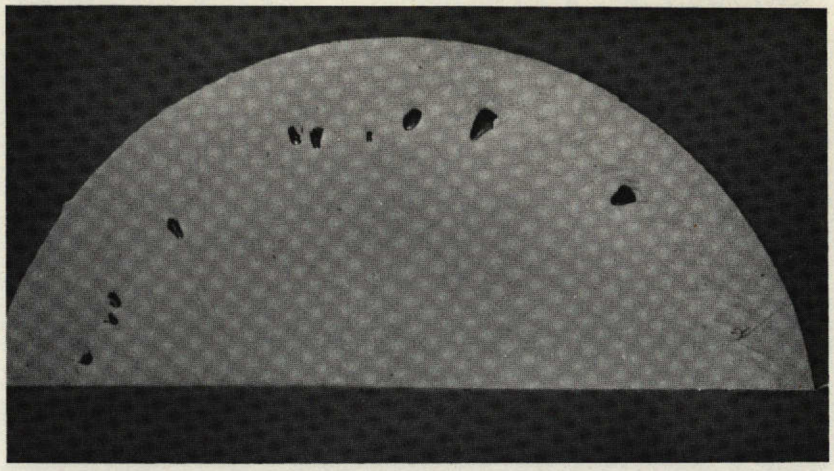


Figure K-4. T-111 Fuel Pin End Cap to Tube Electron Beam Weld - Transverse Section Sample Weld Produced after Observing Defects in Fuel Pins 504A and B



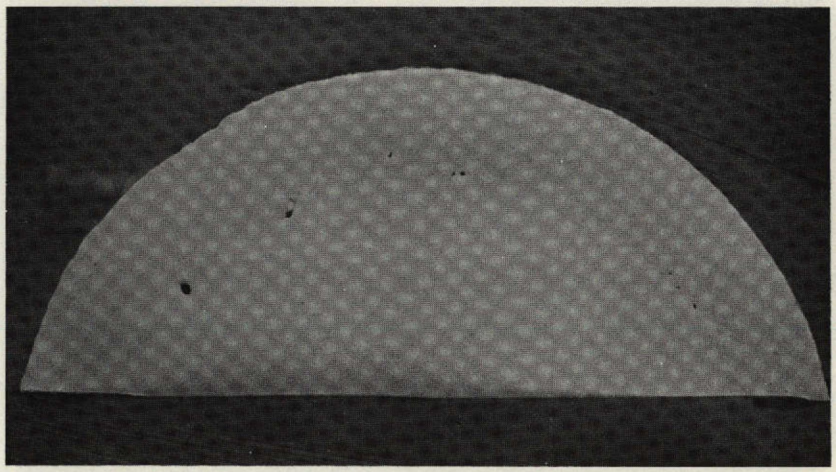
50X

Figure K-5. T-111 Fuel Pin End Cap to Tube
Electron Beam Weld - Longitudinal Section in Root Area
Sample Weld as Noted Above



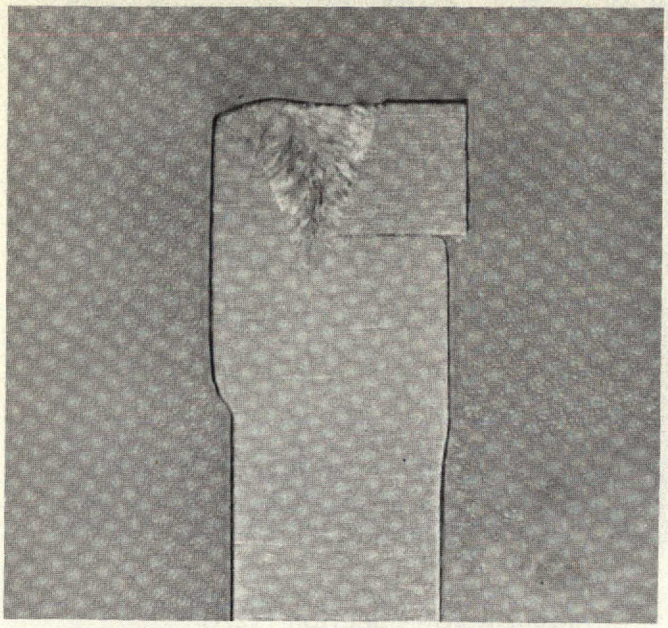
5.75X

Figure K-6. Longitudinal Macrosection of Fuel Pin (504A) End Cap to Tube Electron Beam Weld

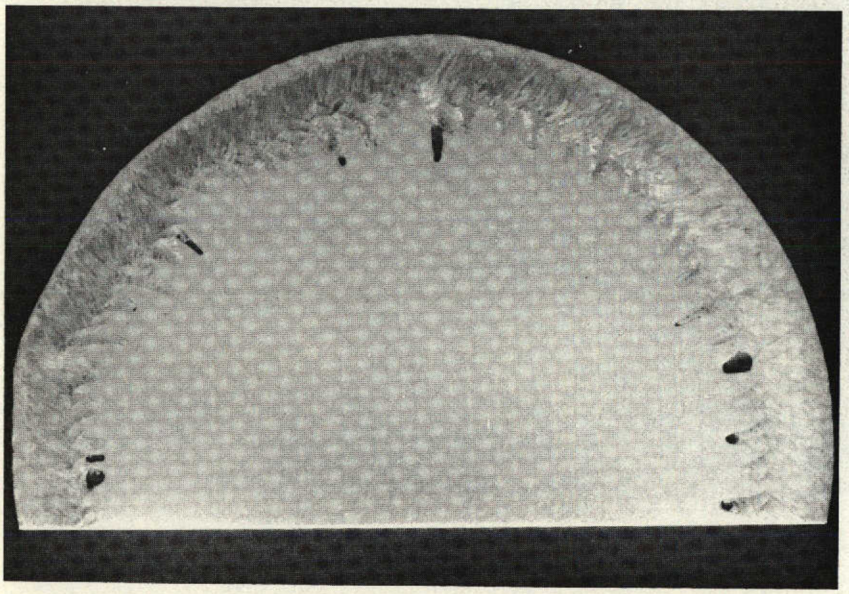


5.75X

Figure K-7. Longitudinal Macrosection of Fuel Pin End Cap to Tube Electron Beam Weld - Sample Joint to Evaluate Reproducibility

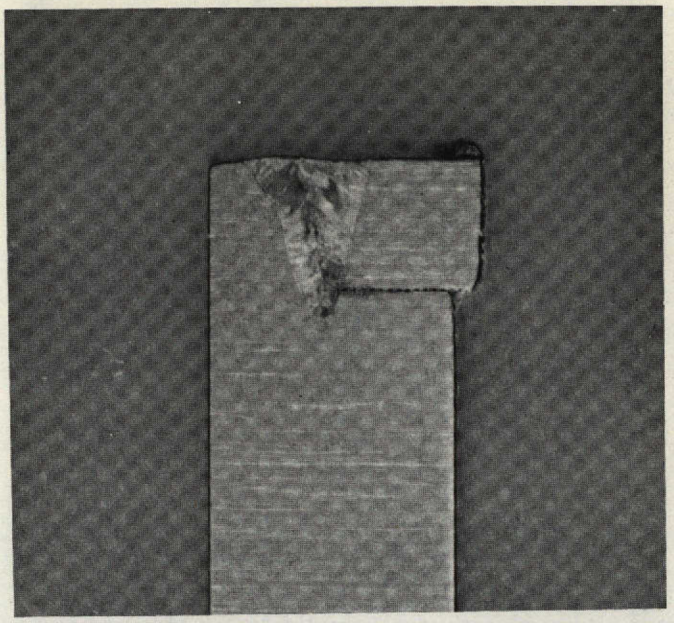


Transverse Weld Section (12X)

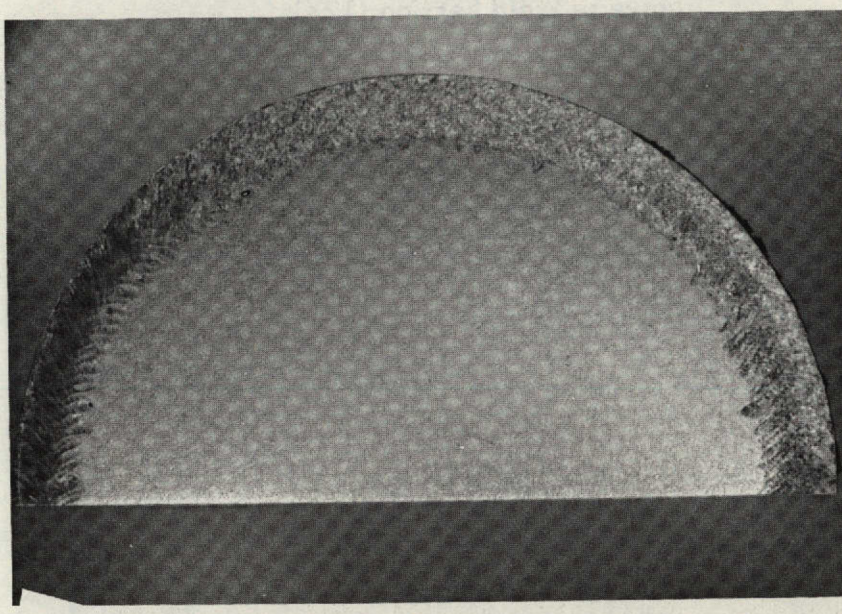


Longitudinal Weld Section (5.5X)

Figure K-8. T-111 End Cap to Tube Weld (D Size)
Condition A (28.5 KV, 98 ma, 60 RPM, Defocused)

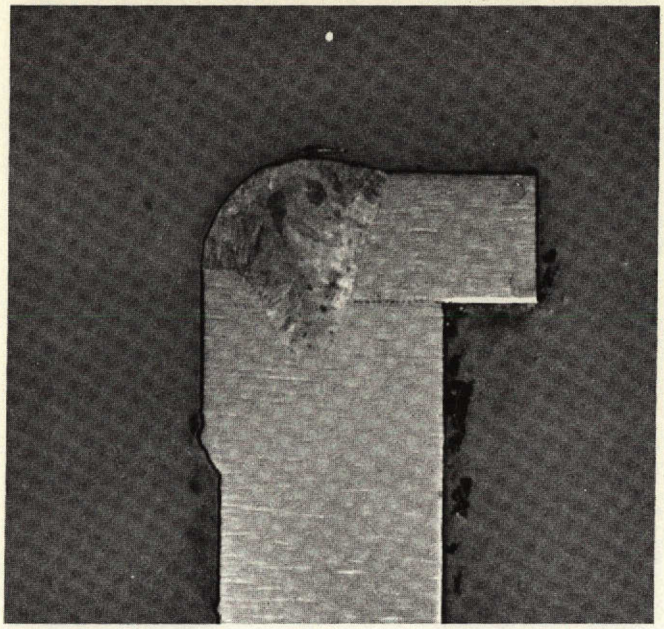


Transverse Weld Section (12X)

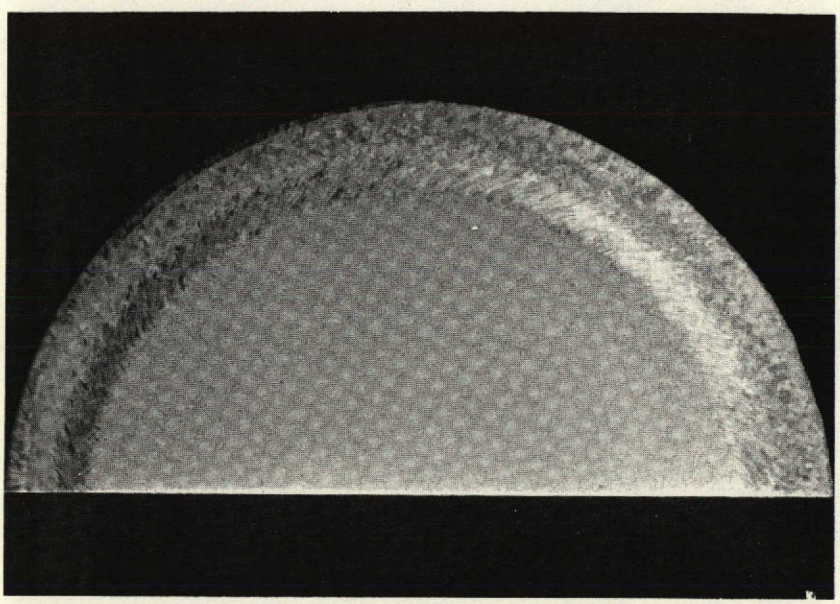


Longitudinal Weld Section (5.5X)

Figure K-9. T-111 End Cap to Tube Weld (D Size)
Condition B (24 KV, 80 ma, 24 RPM, Sharp Focus)



Transverse Weld Section (12X)



Longitudinal Weld Section (5.5X)

Figure K-10. Final Approved Weld Schedule
T-111 End Cap to Tube Weld (D Size)
Condition D (20 KV, 65 ma, 15 RPM, Sharp Focus)